Chemistry 10

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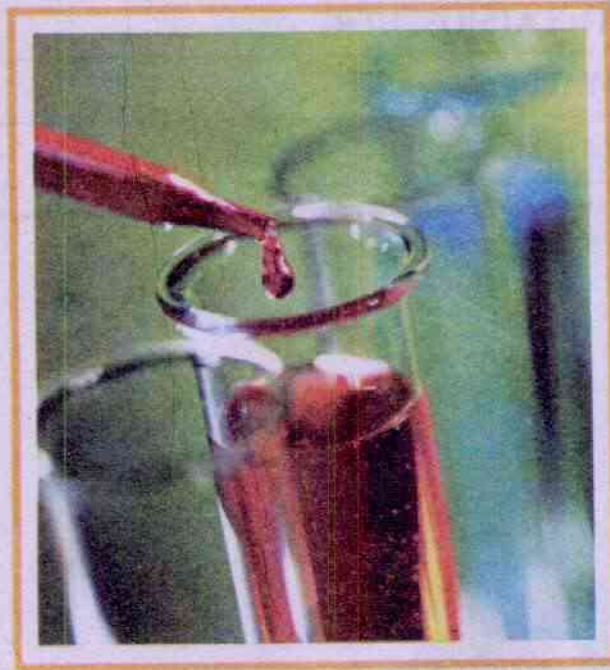
ترجمہ: ”شروع اللہ کے نام سے جو بڑا مہربان نہایت رحم والا ہے۔“

CHEMISTRY

10

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Chapter 9

Chemical Equilibrium

Major Topics

- 9.1 Reversible Reaction and Dynamic Equilibrium
- 9.2 Law of Mass Action and Derivation of the Expression for the Equilibrium Constant
- 9.3 Equilibrium Constant and its Units
- 9.4 Importance of Equilibrium Constant

Time allocation

Teaching periods	08
Assessment periods	03
Weightage	5%

Students Learning Outcomes

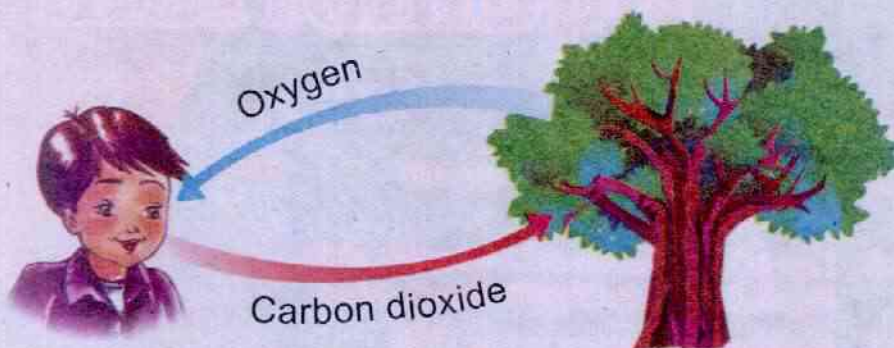
Student will be able to:

- define chemical equilibrium in terms of a reversible reaction. (Understanding);
- write both the forward and the reverse reaction and describe the macroscopic characteristics of each. (Applying);
- define Law of Mass Action. (Understanding);
- derive an expression for the equilibrium constant and its units. (Applying);
- state the necessary condition for the equilibrium and the ways that equilibrium can be recognized.(Understanding) and
- write the equilibrium constant expression of a reaction.

Introduction:

Generally, we presume that most chemical and physical changes proceed to completion. A complete reaction is one in which all reactants have been converted into products. However, most chemical reactions do not go to completion because products react themselves to form the reactants. As a result, after sometime no further change takes place. Quantities of reactants and products remain unchanged, and it seems that the reaction has stopped. In fact, these reactions do not stop; rather they take place on both directions at equal rate and attain the equilibrium state. Such reactions are called reversible reactions.

Many examples of physical and chemical equilibrium are found in nature.

We owe our existence to equilibrium phenomenon taking place in atmosphere. We inhale oxygen and exhale carbon dioxide, while plants consume carbon dioxide and release oxygen. This natural process is responsible for the existence of life on the Earth.

Many environmental systems depend for their existence on delicate equilibrium phenomenon. For example, concentration of gases in lake water is governed by the principles of equilibrium. The lives of aquatic plants and animals are indirectly related to concentration of dissolved oxygen in water.

9.1 REVERSIBLE REACTION AND DYNAMIC EQUILIBRIUM

In a chemical reaction the substances that combine are called reactants and the new substances formed are called products. For example, when H_2 and O_2 (reactants) combine they form H_2O (product).

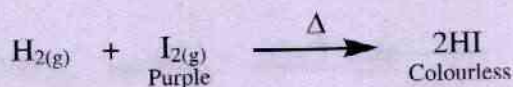
$$2H_{2(g)} + O_{2(g)} \xrightarrow[\text{Heat}]{\text{Pt}} 2H_2O_{(l)}$$

Most of the reactions, *in which the products do not recombine to form reactants, are called* ***irreversible reactions***. They are supposed to complete and are represented by putting a single arrow ($\longrightarrow$) between the reactants and products.

On the other hand, *ctions in which the products can recombine to form reactants are called* ***reversi reactions***. These reactions never go to completion. They are represented by a double arrow ($\rightleftharpoons$) between reactants and products. These reactions proceed in both ways, i.e., they consist of two reactions; forward and reverse. So, a reversible reaction is one which can be made to proceed in either direction depending upon the conditions.

Let us discuss a reaction between hydrogen and iodine. Because one of the reactant, iodine is purple, while the product hydrogen iodide is colourless, proceedings of the reaction are easily observable. On heating, hydrogen and iodine

vapours in a closed flask, hydrogen iodide is formed. As a result, purple colour of iodine fades as it reacts to form colourless hydrogen iodide, as shown in figure 9.1.

$$\underset{}{H_{2(g)}} + \underset{\text{Purple}}{I_{2(g)}} \xrightarrow{\Delta} \underset{\text{Colourless}}{2HI}$$

This reaction is called as **forward reaction.**

On the other hand, when only hydrogen iodide is heated in a closed flask, purple colour appears because of formation of iodine vapours. Such as

$$\underset{\text{Colourless}}{2HI_{(g)}} \xrightarrow{\Delta} H_{2(g)} + \underset{\text{Purple}}{I_{2(g)}}$$

In this case, hydrogen iodide acts as reactant and produces hydrogen and iodine vapours. This reaction is reverse of the above. Therefore, it is called as **reverse reaction.**

When both of these reactions are written together as a reversible reaction, they are represented as:

$$H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$$

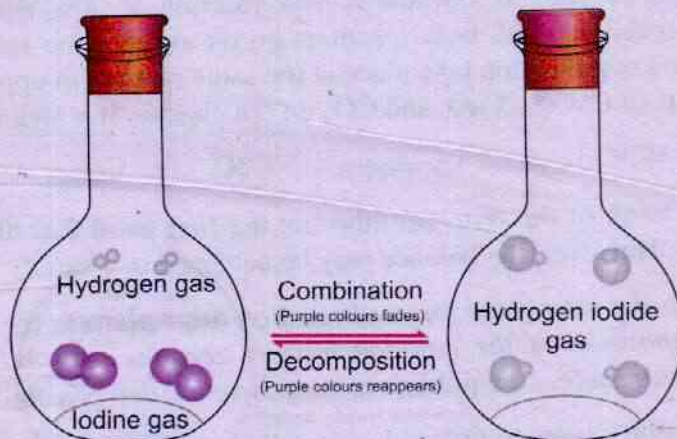



Fig. 9.1 Showing establishment of reversible reaction.

Let us have another example, when calcium oxide and carbon dioxide react, they produce calcium carbonate:

$$CaO_{(s)} + CO_{2\,(g)} \longrightarrow CaCO_{3(s)}$$

On the other hand, when $CaCO_3$ is heated in an open flask, it decomposes to form calcium oxide and carbon dioxide. CO_2 escapes out and reaction goes to completion:

$$CaCO_{3(s)} \longrightarrow CaO_{(s)} + CO_{2(g)}\uparrow \quad \text{(decomposition)}$$

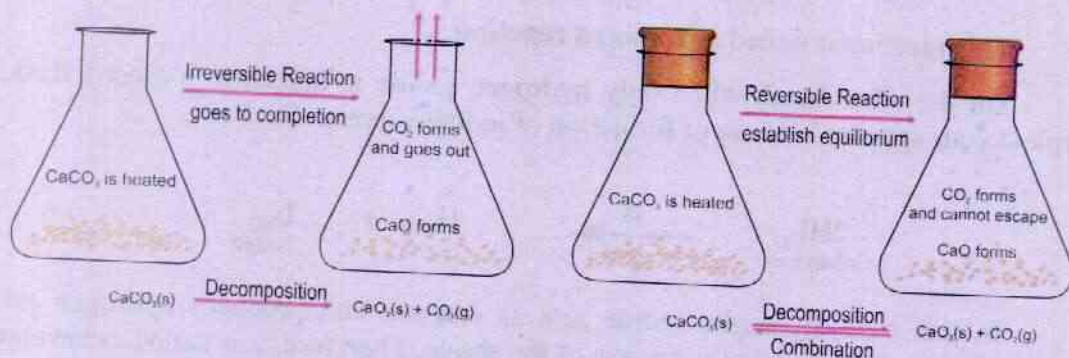
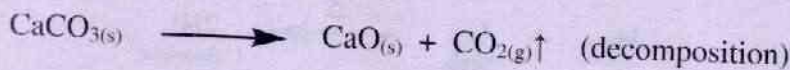
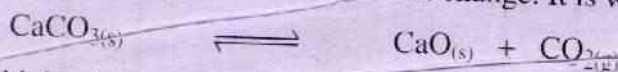



Fig. 9.2 Showing establishment of reversible reaction.

In these two reactions, decomposition is reverse to combination or vice versa. When calcium carbonate is heated in a closed flask, so that CO_2 can't escape out as shown in figure 9.2. Initially only decomposition goes on (forward reaction), but after a while CO_2 starts combining with CaO to form $CaCO_3$ (reverse reaction). In the beginning, forward reaction is fast and reverse reaction is slow. But eventually, the reverse reaction speeds up and both reactions go on at the same rate. At this stage decomposition and combination take place at the same rate but in opposite directions, as a result amounts of $CaCO_3$, CaO and CO_2 do not change. It is written as

$$CaCO_{3(s)} \rightleftharpoons CaO_{(s)} + CO_{2(g)}$$

When we think of the term equilibrium, the first word that usually comes to mind is "balance". However, the balance may be achieved in a variety of ways.

Thus, *when the rate of the forward reaction takes place at the rate of reverse reaction, the composition of the reaction mixture remains constant, it is called a* ***chemical equilibrium state***. At equilibrium state there are two possibilities.

(i) When reaction ceases to proceed, it is called static equilibrium. This happens mostly in physical phenomenon. For example, a building remains standing rather than falling down because all the forces acting on it are balanced. This is an example of static equilibrium.

(ii) *When reaction does not stop, only the rates of forward and reverse reactions become equal to each other but take place in opposite directions. This is called* ***dynamic equilibrium state***. Dynamic means reaction is still continuing. At dynamic equilibrium state:

Rate of forward reaction = Rate of reverse reaction

In a reversible reaction, dynamic equilibrium is established before the completion of reaction. It is represented graphically in figure 9.3. At initial stage the rate of forward reaction is very fast and reverse reaction is taking place at a negligible rate. But gradually forward reaction slows down and reverse reaction speeds up. *Eventually, both reactions attain the same rate, it is called a dynamic equilibrium state.*

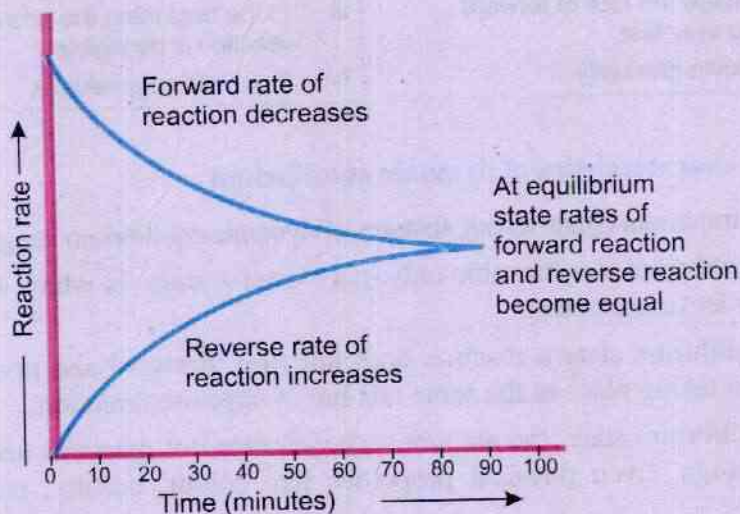



Fig. 9.3 Graph showing the rate of forward and reverse reactions and establishment of equilibrium state

For example, in case of reaction between hydrogen and iodine vapours, some of the molecules react with each other to give hydrogen iodide.

$$H_{2(g)} + I_{2(g)} \longrightarrow 2HI_{(g)}$$

At the same time, some of the hydrogen iodide molecules decompose back to hydrogen and iodine.

$$2HI_{(g)} \longrightarrow H_{2(g)} + I_{2(g)}$$

In the beginning, as the concentration of the reactants is higher than that of the products, the rate of the forward reaction is fast than the reverse reaction. As the reaction proceeds, the concentration of reactants will gradually decrease while that of product will increase, consequently the rate of the forward reaction will go on decreasing and the reverse reaction will go on increasing and ultimately the two rates will become equal to each other. Thus, the equilibrium will set up and concentration of various species (H_2, I_2, HI) becomes constant. It is represented as

$$H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$$

Macroscopic characteristics of forward and reverse reactions

Forward Reaction	Reverse Reaction
i. It is a reaction in which reactants react to form products.	i. It is a reaction in which products react to produce reactants.
ii. It takes place from left to right	ii. It takes place from right to left.
iii. At initial stage the rate of forward reaction is very fast.	iii. In the beginning the rate of reverse reaction is negligible.
iv. It slows down gradually.	iv. It speeds up gradually.

Macroscopic characteristics of dynamic equilibrium

A few important characteristic features of dynamic equilibrium are given below:

(i) An equilibrium is achievable only in a closed system (in which substances can neither leave nor enter).

(ii) At equilibrium state a reaction does not stop. Forward and reverse reactions keep on taking place at the same rate but in opposite direction.

(iii) At equilibrium state, the amount (concentration) of reactants and products do not change. Even physical properties like colour, density, etc. remain the same.

(iv) An equilibrium state is attainable from either way, i.e. starting from reactants or from products.

(v) An equilibrium state can be disturbed and again achieved under the given conditions of concentration, pressure and temperature.

Test yourself 9.1

i. *Why reversible reactions never complete?*

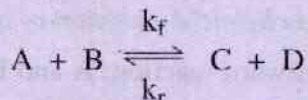
ii. *What is a static equilibrium, explain with an example.*

iii. *Why the amounts of reactants and products do not change in a reversible reaction.*

9.2 LAW OF MASS ACTION

Guldberg and Waage in 1869 put forward this law. According to this law "*The rate at which a substance reacts is directly proportional to its active mass and the rate of a reaction is directly proportional to the product of the active masses of the reacting substances*". Generally, an active mass is considered as the molar concentration having units of mol dm^{-3}, expressed as square brackets [ ].

Consider for example, a reversible reaction of the type

$$A + B \underset{k_r}{\overset{k_f}{\rightleftharpoons}} C + D$$

Suppose [A], [B], [C] and [D] are the molar concentrations (mole dm^{-3}) of A, B, C and D respectively.

According to the Law of Mass Action:

The rate of the forward reaction $\propto$ [A] [B]

$= k_f$ [A] [B]

Similarly,

The rate of the reverse reaction $\propto$ [C] [D]

$= k_r$ [C] [D]

where k_f and k_r are the proportionality constant called specific rate constants of the forward and the reverse reactions respectively.

At equilibrium state:

The rate of forward reaction = The rate of reverse reaction

$$k_f [A] [B] = k_r [C] [D]$$

$$\frac{k_f}{k_r} = \frac{[C] [D]}{[A] [B]}$$

$$\text{Where } K_c = \frac{k_f}{k_r}$$

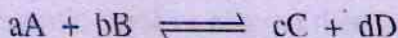
K_c is called equilibrium constant. It is represented as:

$$K_c = \frac{[C] [D]}{[A] [B]}$$

Law of Mass Action describes the relationship between active masses of the reactants and the rate of a reaction.

Derivation of the Expression for Equilibrium Constant for General Reaction

Let us apply the law of Mass Action for a general reaction.

$$aA + bB \rightleftharpoons cC + dD$$

This reaction consists of two reactions; forward and reverse reactions. According to this law, *the rate of a chemical reaction is directly proportional to the*

product of the molar concentrations of its reactants raised to power equal to their number of moles in the balanced chemical equation of the reaction.

Let us first discuss the forward reaction. A and B are the reactants whereas 'a' and 'b' are their number of moles.

The rate of forward reaction according to law of Mass Action is:

$$R_f \propto [A]^a[B]^b$$

$$R_f = k_f [A]^a[B]^b$$

where k_f is the rate constant for the forward reaction.

Similarly, the rate of the reverse reaction R_r, is directly proportional to the product of $[C]^c [D]^d$, where 'c' and 'd' are the number of moles as given in the balanced chemical equation. Thus,

$$R_r \propto [C]^c[D]^d$$

$$R_r = k_r [C]^c [D]^d$$

where k_r is the rate constant for the reverse reaction . We know that at equilibrium state the rates of both the reactions are equal.

The rate of forward the reaction = The rate of the reverse reaction

Such as: $R_f = R_r$

and putting the values of R_f and R_r

$$k_f [A]^a [B]^b = k_r [C]^c [D]^d$$

By taking the constants on one side and the variables on other side of the equation, the above equation becomes:

$$\frac{k_f}{k_r} = \frac{[C]^c [D]^d}{[A]^a[B]^b}$$

$$\text{or} \quad K_c = \frac{[C]^c [D]^d}{[A]^a[B]^b}$$

where, $K_c = \frac{k_f}{k_r}$ is called equilibrium constant.

This expression is for chemical equilibrium constant. All the reversible reactions can be expressed in this form. Such as:

(i) When nitrogen reacts with oxygen to form nitrogen monoxide, the reversible reaction is as follows

$$N_{2(g)} + O_{2(g)} \rightleftharpoons 2NO_{(g)}$$

The rate of forward reaction $R_f = k_f [N_2][O_2]$

The rate of reverse reaction $R_r = k_r [NO]^2$

The equilibrium constant expression for this reaction is:

$$K_c = \frac{[NO]^2}{[N_2][O_2]}$$

(ii) For the reaction of nitrogen with hydrogen to form ammonia, the balanced chemical equation is

$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$$

For the reaction

The rate of forward reaction $R_f = k_f [N_2][H_2]^3$

The rate of reverse reaction $R_r = k_r [NH_3]^2$

The expression for the equilibrium constant for this reaction is:

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3}$$

Test yourself 9.2

i. Define the Law of Mass Action.

ii. How the active mass is represented?

iii. What do you mean by equilibrium constant?

iv. Point out the coefficients of each in the following hypothetical reactions:

a. $2A + 3B \rightleftharpoons 4C + 2D$

b. $4X \rightleftharpoons 2Y + 3Z$

c. $2M + 4N \rightleftharpoons 5O$

v. Write the equilibrium constant expressions for the following reactions:

a. $2NO_{2(g)} \rightleftharpoons N_2O_{4(g)}$

b. $PCl_{3(g)} + Cl_{2(g)} \rightleftharpoons PCl_{5(g)}$

c. $2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$

9.3 EQUILIBRIUM CONSTANT AND ITS UNITS

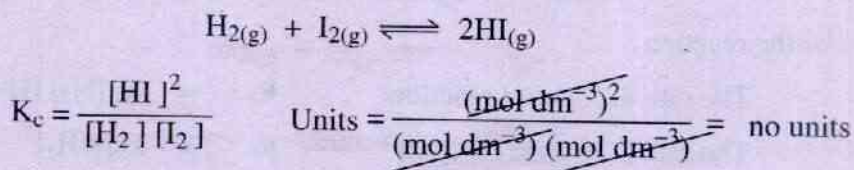
Equilibrium constant *is a ratio of the product of concentration of products raised to the power of coefficient to the product of concentration of reactants raised to the power of coefficient as expressed in the balanced chemical equation.*

$$K_c = \frac{\text{Product of concentration of products raised to the power of coefficients}}{\text{Product of concentration of reactants raised to the power of coefficients}}$$

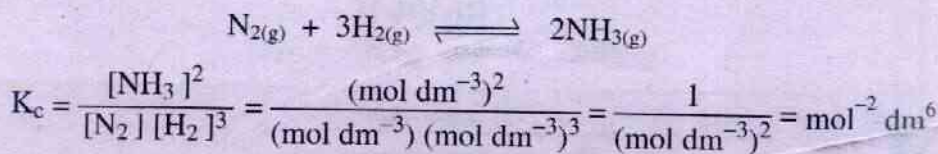
It is conventional to write the products side numerator and reactants as denominator. By knowing the balanced chemical equation for a reversible reaction we can write the equilibrium expression. Thus we can calculate the numerical value of K_c by putting actual equilibrium concentrations of the reactants and products into equilibrium expression. The value of K_c depends only on temperature, it does not depend on the initial concentrations of the reactants and the products. A few problems have been solved to make the concept clean.

K_c has no units in reactions with equal number of moles on both sides of the equation. This is because concentration units cancel out in the expression for K_c, e.g., for the reaction

$$H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$$

$$K_c = \frac{[HI]^2}{[H_2][I_2]} \qquad \text{Units} = \frac{(mol\ dm^{-3})^2}{(mol\ dm^{-3})(mol\ dm^{-3})} = \text{no units}$$

For reactions in which the number of moles of reactants and product are not equal in the balanced chemical equation, K_c of course, have units, e.g., for the reaction

$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$$

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3} = \frac{(mol\ dm^{-3})^2}{(mol\ dm^{-3})(mol\ dm^{-3})^3} = \frac{1}{(mol\ dm^{-3})^2} = mol^{-2}\ dm^6$$

Problem 9.1

When hydrogen reacts with iodine at 25 °C to form hydrogen iodide by a reversible reaction as follows:

$$H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$$

The equilibrium concentrations are:

$[H_2] = 0.05\ mol\ dm^{-3}$; $[I_2] = 0.06\ mol\ dm^{-3}$ and $[HI] = 0.49\ mol\ dm^{-3}$.

Calculate the equilibrium constant for this reaction?

Solution

Given equilibrium concentrations are;

$[H_2] = 0.05\ mol\ dm^{-3}$; $[I_2] = 0.06\ mol\ dm^{-3}$ and $[HI] = 0.49\ mol\ dm^{-3}$

Write the equilibrium constant expression as

$$K_c = \frac{[HI]^2}{[H_2][I_2]}$$

Now put the equilibrium concentration values in the equilibrium expression

$$K_c = \frac{[0.49]^2}{[0.05]\,[0.06]} = \frac{0.2401}{0.0030} = 80$$

Problem 9.2

For the formation of ammonia by Haber's process hydrogen and nitrogen react reversibly at 500 °C as follows

$$N_{2(g)} \quad + \quad 3H_{2(g)} \quad \rightleftharpoons \quad 2NH_{3(g)}$$

The equilibrium concentrations of these gases are: nitrogen 0.602 mol dm^{-3}; hydrogen 0.420 mol dm^{-3} and ammonia 0.113 mol dm^{-3}. What is value of K_c.

Solution

The equilibrium concentrations are

$[N_2]$ = 0.602 mol dm^{-3}, $[H_2]$ = 0.420 mol dm^{-3} and $[NH_3]$ = 0.113 mol dm^{-3}

The equilibrium constant expression for this reaction is:

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3}$$

Now put the equilibrium concentration values into the equilibrium expression

$$K_c = \frac{[0.113]^2}{[0.602]\,[0.420]^3} = 0.286 \ \ mol^{-2}\ dm^6$$

Problem 9.3

For a reaction between PCl_3 and Cl_2 to form PCl_5, the equilibrium constant is 0.13 mol^{-1} dm^3 at a particular temperature. When the equilibrium concentrations of PCl_3 and Cl_2 are 10.0 and 9.0 mol dm^{-3} respectively, what is the equilibrium concentration of PCl_5.

Solution

$[PCl_3]$ = 10 mol dm^{-3} $\qquad$ $[Cl_2]$ = 9.0 mol dm^{-3}

K_c = 0.13 mol^{-1} dm^3 $\qquad$ $[PCl_5]$ = ?

Now write the balanced chemical equation and equilibrium constant expression

$$PCl_{3(g)} \ + \ Cl_{2(g)} \quad \rightleftharpoons \quad PCl_{5(g)}$$

$$K_c = \frac{[PCl_5]}{[PCl_3][Cl_2]}$$

Now put the known values in above equation and rearrange

$$0.13 = \frac{[PCl_5]}{(10.0)(9.0)}$$

$$[PCl_5] = 0.13 \times 10.0 \times 9.0 = 11.7 \text{ mol dm}^{-3}$$

9.4 IMPORTANCE OF EQUILIBRIUM CONSTANT

Knowing the numerical value of equilibrium constant of a chemical reaction, direction as well as extent of the reaction can be predicted.

(i) Predicting Direction of a Reaction

Direction of a reaction at a particular moment can be predicted by inserting the concentration of the reactants and products at that particular moment in the equilibrium expression. Consider the gaseous reaction of hydrogen with iodine.

$$H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)} \quad K_c = 57.0 \text{ at } 700 \text{ K}$$

We withdraw the samples from the reaction mixture and determine the concentrations of $H_{2(g)}$, $I_{2(g)}$ and $HI_{(g)}$. Suppose concentrations of the components of the mixture are:

$[H_2]_t = 0.10 \text{ mol dm}^{-3}$ $[I_2]_t = 0.20 \text{ mol dm}^{-3}$ and $[HI]_t = 0.40 \text{ mol dm}^{-3}$.

The subscript 't' with the concentration symbols means that the concentrations are measured at some time t, not necessarily at equilibrium. When we put these concentrations into the equilibrium constant expression, we obtain a value called the reaction quotient Q_c. The reaction quotient for this reaction is calculated as:

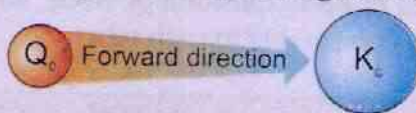
$$Q_c = \frac{[HI]_t^2}{[H_2]_t [I_2]_t} = \frac{(0.40)^2}{(0.10)(0.20)} = 8.0$$

As the numerical value of Q_c (8.0) is less than K_c(57.0), the reaction is not at equilibrium. It requires more concentration of product. Therefore, reaction will move in the forward direction.

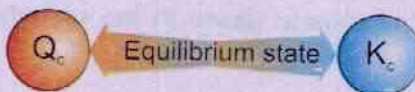
The reaction quotient Q_c is useful because it predicts the direction of the reaction by comparing the value of Q_c with K_c.

Thus, we can make the following generalization about the direction of the reaction.

If $Q_c < K_c$; the reaction goes from left to right, i.e., in forward direction to attain equilibrium.

Q_c Forward direction K_c

If $Q_c > K_c$; the reaction goes from right to left, i.e., in reverse direction to attain equilibrium.

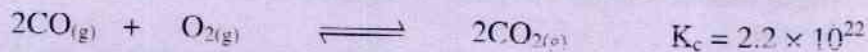
If $Q_c = K_c$; forward and reverse reactions take place at equal rates i.e., equilibrium has been attained.

Q_c Equilibrium state K_c

(ii) Predicting Extent of a Reaction

Numerical value of the equilibrium constant predicts the extent of a reaction. It indicates to which extent reactants are converted to products. In fact, it measures how far a reaction proceeds before establishing equilibrium state.

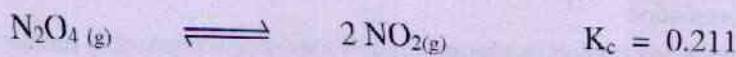
In general, there are three possibilities of predicting extent of reactions as explained below.

(a) **Large numerical value of K_c:** The large value of K_c indicates that at equilibrium position the reaction mixture consists of almost all products and reactants are negligible. *The reaction has almost gone to completion.* For example, oxidation of carbon monoxide goes to completion at 1000 K.

$$2CO_{(g)} + O_{2(g)} \rightleftharpoons 2CO_{2(g)} \qquad K_c = 2.2 \times 10^{22}$$

(b) **Small numerical value of K_c:** When the K_c value of reaction is small, it indicates that the equilibrium has established with a very small conversion of reactants to products. At equilibrium position, almost all reactants are present but amount of products is negligible. *Such type of reactions never go to completion.* For example;

$$2NH_{3(g)} \rightleftharpoons N_{2(g)} + 3H_{2(g)} \qquad K_c = 3.0 \times 10^{-9}$$

(c) **Numerical value of K_c is neither small nor large.** Such reactions have comparable amounts of reactants and products at equilibrium position. For example:

$$N_2O_{4\,(g)} \rightleftharpoons 2\,NO_{2(g)} \qquad K_c = 0.211$$

It indicates that the rates of decomposition of N_2O_4 and combination of NO_2 to form N_2O_4 are almost comparable to each other.

Test yourself 9.3

i. What do you mean by the extent of a reaction?
ii. Why the reversible reactions do not go to completion?
iii. If a reaction has large value of K_c, will it go to completion and why?
iv. Which types of reactions do not go to completion?
v. Why the reaction mixture does not have 50% reactants and 50% products at equilibrium position?

Use of atmospheric gases in the manufacture of chemicals.

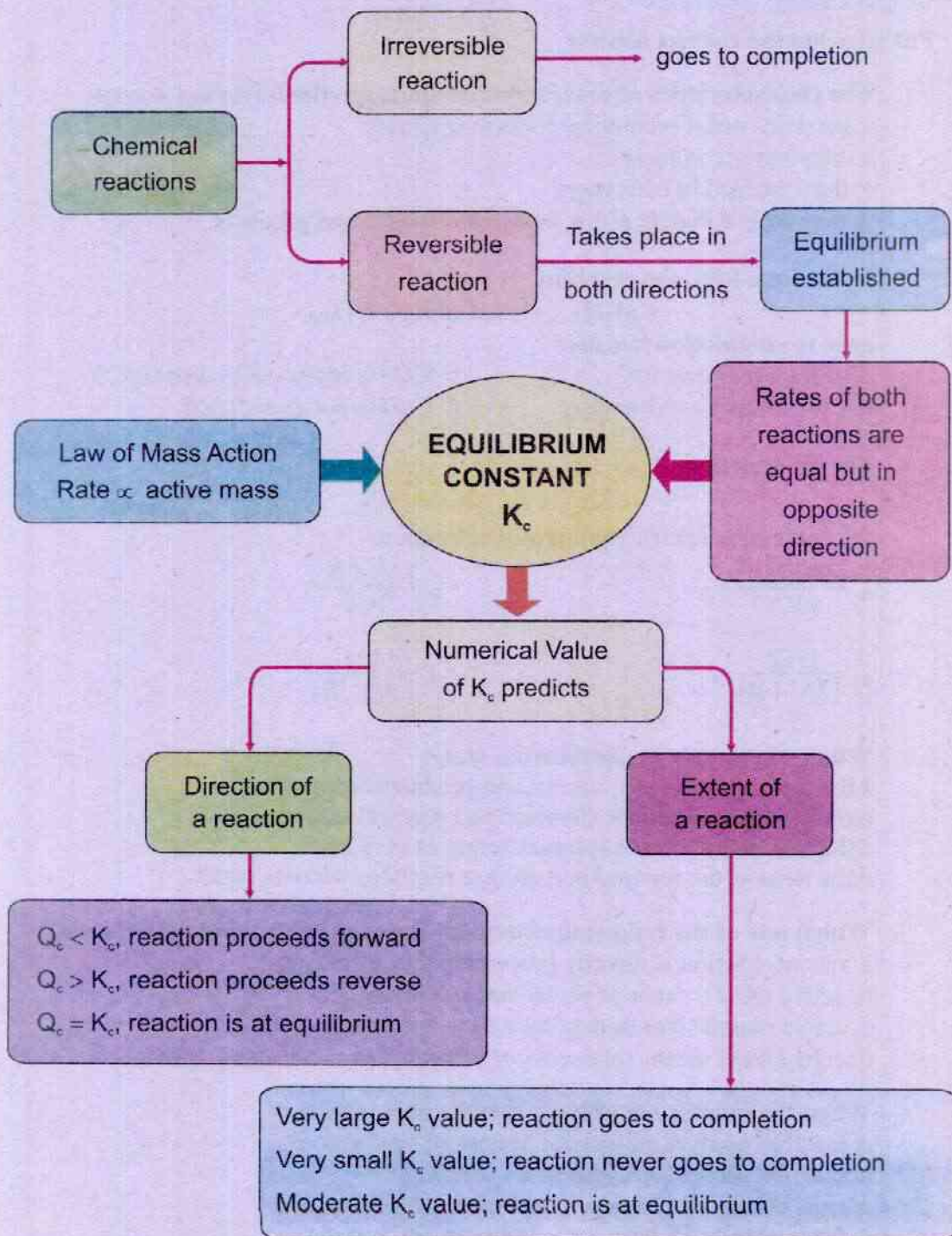
The two major components of atmosphere are nitrogen and oxygen gases. Both of these gases constitute 99% of the atmosphere.

These gases are being used to manufacture chemicals since the advent of 20th century. Nitrogen is used to prepare ammonia, which is further used to manufacture nitrogenous fertilizers.

Oxygen is used to prepare sulphur dioxide which is further used to manufacture king of chemicals sulphuric acid.

Key Points

- Reversible reactions are those in which products recombine to form reactants. These reactions never complete. They proceed in both ways; i.e., forward and reverse.
- Dynamic equilibrium state is one at which forward and reverse reactions proceed at equal rate but in opposite directions so that overall reaction does not stop.
- Equilibrium constant K_c is a ratio of the product of concentration of products raised to the power of coefficients to the product of concentration of reactants raised to the power of coefficients as expressed in the balanced chemical equation.
- Equilibrium constant has no units when number of moles of reactants and products are same.
- By knowing the value of equilibrium, constants the extent of a reaction can be predicted.
- Reactions having large K_c value, proceed almost to completion.
- Reactions having small magnitude of K_c indicates that equilibrium state has established consuming small amount of reactants. Therefore, they never go to completion.
- Reactions having moderate magnitude have comparable amounts of reactants and products at equilibrium state.

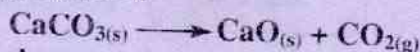
CONCEPT DIAGRAM

EXERCISE

Multiple Choice Questions

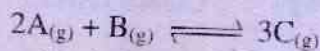
Put a (✓)on the correct answer

1. **The characteristics of reversible reactions are the following except:**
   a. products never recombine to form reactants
   b. they never complete
   c. they proceed in both ways
   d. they have a double arrow between reactants and products

2. **In the lime kiln, the reaction**

$$CaCO_{3(s)} \longrightarrow CaO_{(s)} + CO_{2(g)}$$

   goes to completion because
   a. of high temperature
   b. CaO is more stable than $CaCO_3$
   c. CO_2 escapes continuously
   d. CaO is not dissociated

3. **For the reaction,**

$$2A_{(g)} + B_{(g)} \rightleftharpoons 3C_{(g)}$$

   the expression for the equilibrium constant is:
   a. $\frac{[2A][B]}{[3C]}$
   b. $\frac{[A]^2[B]}{[C]^3}$
   c. $\frac{[3C]}{[2A][B]}$
   d. $\frac{[C]^3}{[A]^2[B]}$

4. **When a system is at equilibrium state:**
   a.the concentration of reactants and products becomes equal
   b.the opposing reactions (forward and reverse) stop
   c.the rate of the reverse reaction becomes very low
   d.the rates of the forward and reverse reactions become equal

5. **Which one of the following statement is not correct about active mass?**
   a. rate of reaction is directly proportional to active mass
   b. active mass is taken in molar concentration
   c. active mass is represented by square brackets
   d. active mass means total mass of substances

6. **When the magnitude of K_c is very large it indicates**
   a. reaction mixture consists of almost all products
   b. reaction mixture has almost all reactants
   c. reaction has not gone to completion
   d. reaction mixture has negligible products

7. **When the magnitude of K_c is very small it indicates**
   a. equilibrium will never establish
   b. all reactants will be converted to products
   c. reaction will go to completion
   d. the amount of products is negligible

8. **Reactions which have comparable amounts of reactants and products at equilibrium state have**
   a. very small K_c value
   b. very large K_c value
   c. moderate K_c value
   d. none of these

9. **At dynamic equilibrium**
   a. the reaction stops to proceed
   b. the amounts of reactants and products are equal
   c. the speeds of the forward and reverse reactions are equal
   d. the reaction can no longer be reversed

10. **In an irreversible reaction dynamic equilibrium**
    a. never establishes
    b. establishes before the completion of reaction
    c. establishes after the completion of reaction
    d. establishes readily

11. **A reverse reaction is one that**
    a. which proceeds from left to right
    b. in which reactants react to form products
    c. which slows down gradually
    d. which speeds up gradually

12. **Nitrogen and hydrogen were reacted together to make ammonia;**

    $$N_2 + 3H_2 \rightleftharpoons 2NH_3 \qquad K_c = 2.86\ mol^{-2}\ dm^6$$

    What will be present in the equilibrium mixture?
    a. NH_3 only
    b. N_2, H_2 and NH_3
    c. N_2 and H_2 only
    d. H_2 only

13. **For a reaction between PCl_3 and Cl_2 to form PCl_5, the units of K_c are:**
    a. $mol\ dm^{-3}$
    b. $mol^{-1}\ dm^{-3}$
    c. $mol^{-1}\ dm^3$
    d. $mol\ dm^3$

Short Questions

1. What are irreversible reactions? Give a few characteristics of them?
2. Define chemical equilibrium state.
3. Give the characteristics of reversible reaction.
4. How is dynamic equilibrium established?
5. Why at equilibrium state reaction does not stop?
6. Why is equilibrium state attainable from either way?
7. What is relationship between active mass and rate of reaction?
8. Derive equilibrium constant expression for the synthesis of ammonia from nitrogen and hydrogen.
9. Write the equilibrium constant expression for the following reactions:
   i. $H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$
   ii. $CO_{(g)} + 3H_{2(g)} \rightleftharpoons CH_{4(g)} + H_2O_{(g)}$
10. How direction of a reaction can be predicted?
11. How can you know that a reaction has achieved an equilibrium state?
12. What are the characteristics of a reaction that establishes equilibrium state at once?
13. If reaction quotient Q_c of a reaction is more than K_c. What will be the direction of the reaction?
14. An industry was established based upon a reversible reaction. It failed to achieve products on commercial level. Can you point out the basic reasons of its failure being a chemist?

Extensive Questions

1. Describe a reversible reaction with the help of an example and graph.
2. Write down the macroscopic characteristics of dynamic equilibrium.
3. State the law of Mass Action and derive the expression for equilibrium constant for a general reaction.
4. What is the importance of equilibrium constant?

Numericals

1. For the decomposition of dinitrogen oxide (N_2O) into nitrogen and oxygen reversible reaction takes place as follows:

$$2N_2O_{(g)} \rightleftharpoons 2N_{2(g)} + O_{2(g)}$$

The concentration of N_2O, N_2 and O_2 are 1.1 mol dm^{-3}, 3.90 mol dm^{-3} and 1.95 mol dm^{-3}, respectively, at equilibrium. Find out K_c for this reaction.

2. Hydrogen iodide decomposes to form hydrogen and iodine. If the equilibrium concentration of HI is 0.078 mol dm^{-3}, H_2 and I_2 is same 0.011 mol dm^{-3}. Calculate the equilibrium constant value for this reversible reaction:

3. For the fixation of nitrogen following reaction takes place:

$$N_{2(g)} + O_{2(g)} \rightleftharpoons 2NO_{(g)}$$

When the reaction takes place at 1500 K, the K_c for this is 1.1×10^{-5}. If equilibrium concentrations of nitrogen and oxygen are 1.7×10^{-3} mol dm^{-3} and 6.4×10^{-3}mol dm^{-3}, respectively, how much NO is formed?

4. When nitrogen reacts with hydrogen to form ammonia, the equilibrium mixture contains 0.31 mol dm^{-3} and 0.50 mol dm^{-3} of nitrogen and hydrogen respectively. If the K_c is 0.50 $mol^{-2}dm^{6}$, what is the equilibrium concentration of ammonia?

Chapter 10

Acids, Bases and Salts

Major Topics

Time allocation

Teaching periods	16
Assessment periods	03
Weightage	7%

Students Learning Outcomes

Student will be able to:

- define and give examples of Arrhenius acids and bases. (Understanding);
- use the Bronsted-Lowry theory to classify substances as acids or bases, as proton donors or proton acceptors. (Applying);
- classify substances as Lewis acids or bases. (Analyzing);
- write the equation for the self-ionization of water. (Remembering);
- given the hydrogen or hydroxide ion concentration, classify a solution as neutral, acidic, or basic. (Applying) and
- complete and balance a neutralization reaction. (Applying)

Introduction:

Acids, bases and salts are three distinct classes in which almost all the organic and inorganic compounds are classified. A famous Muslim Chemist Jabir Bin Hayan prepared nitric acid (HNO_3), hydrochloric acid (HCl) and sulphuric acid (H_2SO_4). In 1787, Lavoisier named binary compounds of oxygen such as CO_2 and SO_2 as acids which on dissolution in water gave acidic solutions. Later on in 1815, Sir Humphrey Davy discovered that there are certain acids which are without oxygen, e.g., HCl. Davy proved the presence of hydrogen as the main constituent of all acids. It was also discovered that all water soluble metallic oxides turn red litmus blue, which is a characteristics of bases. The word acid is derived from the Latin word 'Acidus' meaning sour. The first acid known to man was acetic acid, i.e., in the form of vinegar.

We all have a little concentration of hydrochloric acid in our stomach, which helps to break down the food. Sometimes, the amount of stomach acid becomes too much, which causes 'acidity'. This uncomfortable feeling is easily treated by taking an alklaline medicine. The alkali neutralizes the acid, producing a harmless chemical called a salt.

10.1 CONCEPTS OF ACIDS AND BASES

Acids and bases are recognized by their characteristic properties, such as:

Acids	Bases
i. Acids have sour taste. For example, unripe citrus fruits or lemon juice. ii. They turn blue litmus red. iii. They are corrosive in concentrated form. iv. Their aqueous solutions conduct electric current.	i. Bases have bitter taste and feel slippery, for example, soap is slippery to touch. ii. They turn red litmus blue. iii. They are non-corrosive except concentrated forms of NaOH and KOH. iv. Their aqueous solutions conduct electric current.

10.1.1 Arrhenius Concept of Acids and Bases

According to Arrhenius concept (1787):

***Acid** is a substance which dissociates in aqueous solution to give hydrogen ions.*

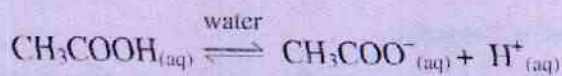
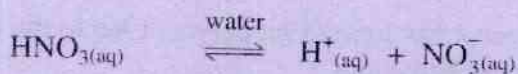
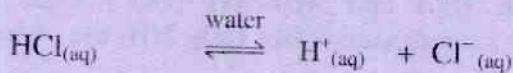
In general the ionization of acids, take place as follows.

$$HA_{(aq)} \xrightleftharpoons{\text{water}} H^+_{(aq)} + A^-_{(aq)}$$

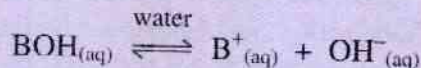
For example, substances such as HCl, HNO_3, CH_3COOH, HCN, etc., are acids because they ionize in aqueous solutions to provide H^+ ions.

$$HCl_{(aq)} \xrightleftharpoons{\text{water}} H^+_{(aq)} + Cl^-_{(aq)}$$

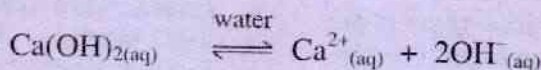
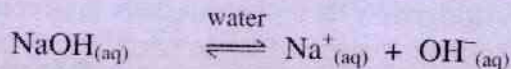
$$HNO_{3(aq)} \xrightleftharpoons{\text{water}} H^+_{(aq)} + NO^-_{3(aq)}$$

$$CH_3COOH_{(aq)} \xrightleftharpoons{\text{water}} CH_3COO^-_{(aq)} + H^+_{(aq)}$$

On the other hand, ***base** is a substance which dissociates in aqueous solution to give hydroxide ions.*

The general ionization of bases take place as follows;

$$BOH_{(aq)} \xrightleftharpoons{water} B^{+}_{(aq)} + OH^{-}_{(aq)}$$

The substances such as NaOH, KOH, NH_4OH, $Ca(OH)_2$ etc. are bases because these compounds ionize in aqueous solutions to provide OH^- ions.

$$NaOH_{(aq)} \xrightleftharpoons{water} Na^{+}_{(aq)} + OH^{-}_{(aq)}$$

$$Ca(OH)_{2(aq)} \xrightleftharpoons{water} Ca^{2+}_{(aq)} + 2OH^{-}_{(aq)}$$

Thus, according to Arrhenius Concept:

Acids give H^+ ions in water, bases give OH^- ions in water.

Examples of some important acids and bases are given in Table 10.1.

Table 10.1 Acids and Bases

Acids	Bases
Hydrochloric acid, HCl	Sodium hydroxide, NaOH
Nitric acid, HNO_3	Potassium hydroxide, KOH
Sulphuric acid, H_2SO_4	Calcium hydroxide, $Ca(OH)_2$
Phosphoric acid, H_3PO_4	Aluminium hydroxide, $Al(OH)_3$

Limitations of Arrhenius Concept

(i) This concept is applicable only in aqueous medium and does not explain nature of acids and bases in non-aqueous medium.

(ii) According to this concept, acids and bases are only those compounds which contain hydrogen (H^+) and hydroxyl (OH^-) ions, respectively. It can't explain the nature of compounds like CO_2, NH_3 etc., which are acid and base, respectively.

Although this concept has limited scope yet, it led to the development of more general theories of acid-base behaviour.

10.1.2 Bronsted-Lowry Concept

In 1923, the Danish chemist Bronsted and the English chemist Lowry independently presented their theories of acids and bases on the basis of proton-transfer. According to this concept:

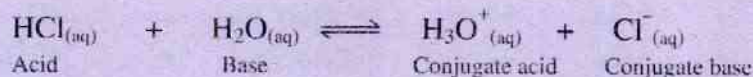
*An **acid** is a substance (molecule or ion) that can donate a proton (H^+) to another substance.*

*A **base** is a substance that can accept a proton (H^+) from another substance.*

For example, HCl acts as an acid while NH_3 acts as a base:

$$HCl_{(aq)} + NH_{3(aq)} \rightleftharpoons NH_4^+{}_{(aq)} + Cl^-{}_{(aq)}$$

Similarly, when HCl dissolves in water; HCl acts as an acid and H_2O as a base.

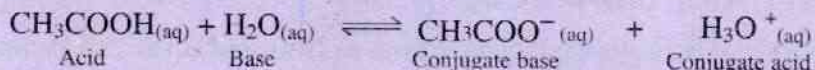
$$\underset{\text{Acid}}{HCl_{(aq)}} + \underset{\text{Base}}{H_2O_{(aq)}} \rightleftharpoons \underset{\text{Conjugate acid}}{H_3O^+{}_{(aq)}} + \underset{\text{Conjugate base}}{Cl^-{}_{(aq)}}$$

It is a reversible reaction. In the forward reaction HCl is an acid as it donates a proton, whereas H_2O is a base as it accepts a proton. In the reverse reaction Cl^- ion is a base as it accepts a proton from acid H_3O^+ ion. Cl^- ion is called a conjugate base of acid HCl and H_3O^+ ion is called a conjugate acid of base H_2O. It means every acid produces a conjugate base and every base produces a conjugate acid such that there is conjugate acid-base pair. Conjugate means joined together as a pair.

A conjugate acid is a specie formed by accepting a proton by a base.

A conjugate base is a specie formed by donating a proton by an acid.

Thus, conjugate acid-base pair differs from one another only by a single proton.

Similarly,

$$\underset{\text{Acid}}{CH_3COOH_{(aq)}} + \underset{\text{Base}}{H_2O_{(aq)}} \rightleftharpoons \underset{\text{Conjugate base}}{CH_3COO^-{}_{(aq)}} + \underset{\text{Conjugate acid}}{H_3O^+{}_{(aq)}}$$

According to Bronsted-Lowry concept, an acid and a base always work together to transfer a proton. That means, a substance can act as an acid (proton donor) only when another substance simultaneously behaves as a base (proton acceptor). Hence, a substance can act as an acid as well as a base, depending upon the nature of the other substance. For example, H_2O acts as a base when it reacts with HCl as stated above and as an acid when it reacts with ammonia such as:

$$H_2O_{(l)} + NH_{3(aq)} \rightleftharpoons NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$$

*Such a substance that can behave as an acid, as well as, a base is called **amphoteric**.*

It has been observed that there are certain substances which behave as acids though they do not have the ability to donate a proton, e.g., SO_3. Similarly, CaO behaves as a base but it cannot accept a proton. These observations prove the limitations of Bronsted-Lowry concept of acids and bases.

Do you know

All Arrhenius acids are Bronsted-Lowry acids, but except OH^-, other Bronsted-Lowry bases are not Arrhenius bases.

Table 10.2 Conjugate acid-base pairs of common species

Acid		Base		Conjugate acid		Conjugate base
$HNO_{3(aq)}$	+	$H_2O_{(l)}$	$\rightleftharpoons$	$H_3O^+{}_{(aq)}$	+	$NO_3^-{}_{(aq)}$
$H_2SO_{4(aq)}$	+	$H_2O_{(l)}$	$\rightleftharpoons$	$H_3O^+{}_{(aq)}$	+	$HSO_4^-{}_{(aq)}$
$HCN_{(aq)}$	+	$H_2O_{(l)}$	$\rightleftharpoons$	$H_3O^+{}_{(aq)}$	+	$CN^-{}_{(aq)}$
$CH_3COOH_{(aq)}$	+	$H_2O_{(l)}$	$\rightleftharpoons$	$H_3O^+{}_{(aq)}$	+	$CH_3COO^-{}_{(aq)}$
$H_2O_{(l)}$	+	$NH_{3(aq)}$	$\rightleftharpoons$	$NH_4^+{}_{(aq)}$	+	$OH^-{}_{(aq)}$
$H_2O_{(l)}$	+	$CO_3^{2-}{}_{(aq)}$	$\rightleftharpoons$	$HCO_3^-{}_{(aq)}$	+	$OH^-{}_{(aq)}$
$HCl_{(l)}$	+	$HCO_3^-{}_{(aq)}$	$\rightleftharpoons$	$H_2CO_{3(aq)}$	+	$Cl^-{}_{(aq)}$

Problem 10.1

(a) *What are conjugate bases of each of the following?*

HS^-, H_3O^+, $H_2PO_4^-$, HSO_4^-, HF, CH_3COOH, $[Al(H_2O)_6)]^{3+}$

(b) Give the conjugate acids of the following:

OH^-, HCO_3^-, HPO_4^{2-}, CH_3NH_2, CO_3^{2-}, CH_3COOH

(c) Which of the following behave both as Bronsted acids and Bronsted bases?

H_2O, HCO_3^-, H_2SO_4, H_3PO_4, HS^-

Solution

(a)	Conjugate bases:	(b)	Conjugate acids
HS	: S^{2-}	OH^-	: H_2O
H_3O^+	: H_2O	HCO_3^-	: H_2CO_3
$H_2PO_4^-$	: HPO_4^{2-}	HPO_4^{2-}	: $H_2PO_4^-$
HSO_4^-	: SO_4^{2-}	CH_3NH_2	: $CH_3NH_3^+$
HF	: F^-		
CH_3COOH	: CH_3COO^-	CO_3^{2-}	: CHO_3^-
$[Al(H_2O)_6]^{3+}$	: $[Al(H_2O)_5OH]^{2+}$	CH_3COOH	: $CH_3COOH_2^+$

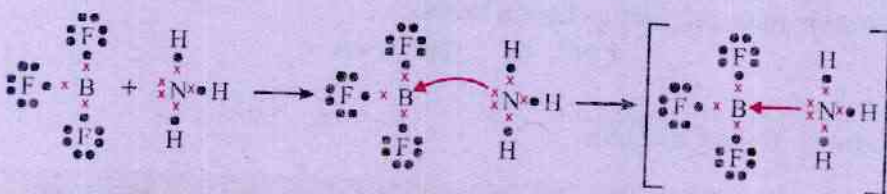
(c) Bronsted acids, as well as, bases are: H_2O, HCO_3^-, HS^-

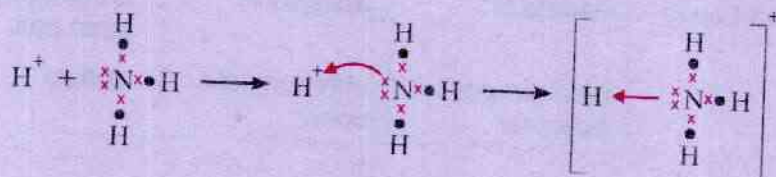
10.1.3 Lewis Concept of Acids and Bases

The Arrhenius and Bronsted-Lowry concepts of acids and bases are limited to substances which contain protons. G.N. Lewis (1923) proposed a more general and broader concept of acids and bases. According to this concept:

An acid *is a substance (molecule or ion) which can accept a pair of electrons, while a* **base** *is a substance (molecule or ion) which can donate a pair of electrons.*

For example, a reaction between ammonia and boron trifluoride takes place by forming a coordinate covalent bond between ammonia and boron trifluoride by donating an electron pair of ammonia and accepting that electron pair by boron trifluoride.

$$BF_3 + NH_3 \longrightarrow BF_3 \; NH_3 \longrightarrow [F_3B \leftarrow NH_3]$$

The cations (proton itself or metal ions) act as Lewis acids. For example a reaction between H^+ and NH_3, where H^+ acts as an acid and ammonia as a base.

$$H^+ + NH_3 \longrightarrow H^+ \; NH_3 \longrightarrow [H \leftarrow NH_3]^+$$

The product of any Lewis acid-base reaction is a single specie, called an ***adduct.*** So, a neutralization reaction according to Lewis concept is donation and acceptance of an electron pair to form a coordinate covalent bond in an adduct.

Acids are electron pair *acceptors* while bases are electron pair donors. Thus, it is evident that any substance which has an unshared pair of electrons can act as a **Lewis base** while a substance which has an empty orbital that can accommodate a pair of electrons acts as **Lewis acid.** Examples of Lewis acids and bases are given below:

Lewis acids. According to Lewis concept, the following species can act as Lewis acids:

(i) *Molecules in which the central atom has incomplete octet.* For example, in BF_3, $AlCl_3$, $FeCl_3$, the central atoms have only six electrons around them, therefore, these can accept an electron pair.

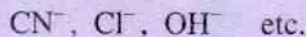
(ii) *Simple cations can act as Lewis acids.* All cations act as Lewis acids since they are deficient in electrons. However, cations such as Na^+, K^+, Ca^{2+} ions, etc., have a very little tendency to accept electrons. While the cations like H^+, Ag^+ ions, etc., have a greater electron accepting tendency therefore, act as Lewis acids.

Lewis bases. According to Lewis concept, the following species can act as Lewis bases:

(i) Neutral species having at least one lone pair of electrons. For example, ammonia, amines, alcohols etc., act as Lewis bases because they contain a lone pair of electrons:

$$\ddot{N}H_3, \quad R—\ddot{N}H_2, \qquad R—\ddot{\underset{\cdot\cdot}{O}}—H$$

(ii) Negatively charged species or anions. For example, chloride, cyanide, hydroxide ions, etc., act as Lewis bases:

$$CN^-, \ Cl^-, \ OH^- \quad \text{etc.}$$

Summary of the Concepts.

Concept	Acid	Base	Product
Arrhenius	gives H^+	gives OH^-	salt + H_2O
Bronsted-Lowry	donate H^+	accepts H^+	conjugate acid-base pair
Lewis	electron pair acceptor	electron pair donor	adduct

Do you know

It may be noted that **all Bronsted bases are also Lewis bases but all Bronsted acids are not Lewis acids.** According to Bronsted concept, a base is a substance which can accept a proton, while according to Lewis concept, a base is a substance which can donate a pair of electrons. Lewis bases generally contain one or more lone pair of electrons and, therefore, they can also accept a proton (Bronsted base). Thus, all Lewis bases are also Bronsted bases. On the other hand, Bronsted acids are those which can give a proton. For example, HCl, H_2SO_4 are not capable of accepting a pair of electrons. Hence, all Bronsted acids are not Lewis acids.

i. *What is the difference between Arrhenius base and Bronsted-Lowry base?*

ii. *What do you mean by neutralization reaction according to Arrhenius acid-base concept?*

iii. *Prove that water is an amphoteric specie.*

iv. *How can you justify that NH_3 is Bronsted-Lowry base but not Arrhenius base?*

v. *State and explain the neutralization reaction according to Lewis concept.*

vi. *Define and give the characteristics of a Lewis acid.*

vii. *Why BF_3 behaves as a Lewis acid?*

viii. *Water is an amphoteric specie according to Bronsted-Lowry concept. What is its nature according to Lewis concept?*

10.1.4 General Properties of Acids

Physical Properties

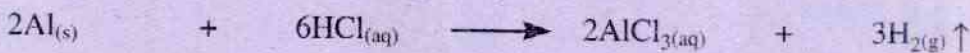
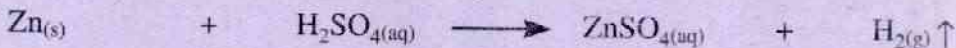
Physical properties of acids have been described in the beginning of the chapter.

Chemical Properties

(i) Reaction with Metals

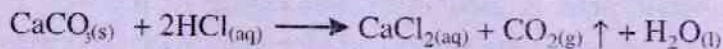
Acids react explosively with metals like sodium, potassium and calcium. However, dilute acids (HCl, H_2SO_4) react moderately with reactive metals like:
Mg, Zn, Fe and Al to form their respective salts with the evolution of hydrogen gas.

$$Zn_{(s)} + H_2SO_{4(aq)} \longrightarrow ZnSO_{4(aq)} + H_{2(g)}\uparrow$$

$$2Al_{(s)} + 6HCl_{(aq)} \longrightarrow 2AlCl_{3(aq)} + 3H_{2(g)}\uparrow$$

(ii) Reaction with Carbonates and Bicarbonates

Acids react with carbonates and bicarbonates to form corresponding salts with the evolution of carbon dioxide gas.

$$CaCO_{3(s)} + 2HCl_{(aq)} \longrightarrow CaCl_{2(aq)} + CO_{2(g)}\uparrow + H_2O_{(l)}$$

$$2NaHCO_{3(aq)} + H_2SO_{4(aq)} \longrightarrow Na_2SO_{4(aq)} + 2CO_{2(g)}\uparrow + 2H_2O_{(l)}$$

(iii) Reaction with Bases

Acids react, with bases (oxides and hydroxides of metal and ammonium hydroxide) to form salts and water. This process is called neutralization.

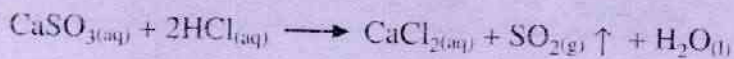
$$NaOH_{(aq)} + HCl_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$$

$$CuO_{(s)} + H_2SO_{4(aq)} \longrightarrow CuSO_{4(aq)} + H_2O_{(l)}$$

(iv) Reaction with Sulphites and Bisulphites

Acids react with sulphites and bisulphites to form salts with the liberation of sulphur dioxide gas.

$$CaSO_{3(aq)} + 2HCl_{(aq)} \longrightarrow CaCl_{2(aq)} + SO_{2(g)}\uparrow + H_2O_{(l)}$$

$$NaHSO_{3(aq)} + HCl_{(aq)} \longrightarrow NaCl_{(aq)} + SO_{2(g)}\uparrow + H_2O_{(l)}$$

(v) Reaction with Sulphides

Acids react with metal sulphides to liberate hydrogen sulphide gas.

$$FeS_{(s)} + H_2SO_{4(aq)} \longrightarrow FeSO_{4(aq)} + H_2S_{(g)}\uparrow$$

Do you know

Following acids are called mineral acids.

Hydrochloric acid (HCl)

Sulphuric acid (H_2SO_4)

Nitric acid (HNO_3)

Uses of Acids

(i) **Sulphuric acid** is used to manufacture fertilizers, ammonium sulphate, calcium superphosphate, explosives, paints, dyes, drugs. It is also used as an electrolyte in lead storage batteries.

(ii) **Nitric acid** is used in manufacturing of fertilizer (ammonium nitrate), explosives, paints, drugs and etching designs on copper plates.

(iii) **Hydrochloric acid** is used for cleaning metals, tanning and in printing industries.

(iv) **Benzoic acid** is used for food preservation.

(v) **Acetic acid** is used for flavouring food and food preservation. It is also used to cure the sting of wasps.

Do you know

Naturally Occurring Acids

	Acid	Source
i.	Citric acid	Citrus fruits i.e., lemon, oranges
ii.	Lactic acid	sour milk
iii.	Formic acid	stings of bees and ants
iv.	Butyric acid	Rancid butter
v.	Tartaric acid	Tamarind, grapes, apples
vi.	Malic acid	Apples
vii.	Uric acid	Urine
viii.	Stearic acid	Fats

10.1.5 General Properties of Bases

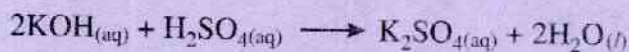
Physical Properties

The physical properties of bases have been described in the beginning of the chapter.

Chemical Properties

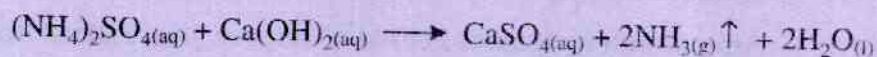
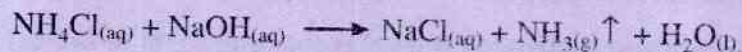
(i) Reaction with Acids

Bases react with acid to form salt and water. It is a neutralization reaction.

$$2KOH_{(aq)} + H_2SO_{4(aq)} \longrightarrow K_2SO_{4(aq)} + 2H_2O_{(l)}$$

(ii) Reaction with Ammonium Salts

Alkalies react with ammonium salts to liberate ammonia gas:

$$NH_4Cl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + NH_{3(g)}\uparrow + H_2O_{(l)}$$

$$(NH_4)_2SO_{4(aq)} + Ca(OH)_{2(aq)} \longrightarrow CaSO_{4(aq)} + 2NH_{3(g)}\uparrow + 2H_2O_{(l)}$$

(iii) Precipitation of Hydroxides

Alkalis precipitate insoluble hydroxides when added to solutions of salts of heavy metals such as copper, iron, zinc, lead and calcium.

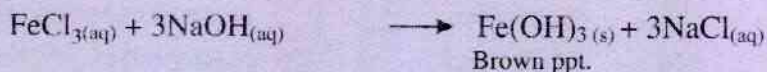
$$CuSO_{4(aq)} + 2NaOH_{(aq)} \longrightarrow Cu(OH)_{2(s)} + Na_2SO_{4(aq)}$$
Blue ppt.

$$ZnCl_{2(aq)} + 2NaOH_{(aq)} \longrightarrow Zn(OH)_{2(s)} + 2NaCl_{(aq)}$$
White ppt.

$$FeCl_{3(aq)} + 3NaOH_{(aq)} \longrightarrow Fe(OH)_{3(s)} + 3NaCl_{(aq)}$$
Brown ppt.

$$Pb(NO_3)_{2(aq)} + 2NaOH_{(aq)} \longrightarrow Pb(OH)_{2(s)} + 2NaNO_{3(aq)}$$
White ppt.

$$CaCl_{2(aq)} + 2NaOH_{(aq)} \longrightarrow Ca(OH)_{2(s)} + 2NaCl_{(aq)}$$
White ppt.

$$FeSO_{4(aq)} + 2NaOH_{(aq)} \longrightarrow Fe(OH)_{2(s)} + Na_2SO_{4(aq)}$$
Dirty Green

Uses of Bases

(i) **Sodium hydroxide** is used for manufacturing of soap.

(ii) **Calcium hydroxide** is used for manufacturing of bleaching powder, softening of hard water and neutralizing acidic soil and lakes due to acid rain.

(iii) **Potassium hydroxide** is used in alkaline batteries.

(iv) **Magnesium hydroxide** is used as a base to neutralize acidity in the stomach. It is also used for the treatment of bee's stings.

(v) **Aluminium hydroxide** is used as foaming agent in fire extinguishers.

(vi) **Ammonium hydroxide** is used to remove grease stains from clothes.

i. When acids react with carbonates and bicarbonates, which gas evolves out?

ii. Which types of salts produce SO_2 gas on reacting with acids?

iii. Give the uses of sulphuric acid.

iv. Name the gas liberated when alkalies react with ammonium salts.

v. Write down the colours of the precipitates formed by reaction of aqueous caustic soda with solutions of:

copper, zinc and ferric salts.

vi. Name an alkali used in alkaline batteries.

Stomach acidity

Stomach secretes chemicals in a regular way to digest food. These chemicals mainly consist of hydrochloric acid along with other salts. Although hydrochloric acid is highly corrosive, but stomach is protected from its effects because it is lined with cells that produce a base. The base neutralizes stomach acid. The important function of this acid is to break down chemical bonds of foods in the digestion process. Thus, big molecules of food are converted into small ones. It also kills the harmful bacteria of certain foods and drinks.

However, sometimes stomach produces too much acid. It causes stomach acidity also called hyperacidity. Symptoms of this disease are feeling burning sensation throughout the gastro intestinal track. These feelings sometimes extend towards the chest, that is called heart burning.

The best prevention from hyperacidity is:

i) Avoiding over-eating and staying away from fatty acids and spicy foods.

ii) Simple and regular eating, remaining in an upright position for about 45 minutes after taking a meal.

iii) Keeping the head elevated while sleeping.

Process of Etching in Art and Industry:

The process of etching on glass is carried out by using a wax stencil. Stencil is placed on areas of glass or mirror that are to be saved from acid. The glass or mirror is dipped into hydrofluoric acid. The acid dissolves the exposed part of the glass thus etching it. This process has been very dangerous because the acid would damage the skin and tissue of artist's body. Although, it is dangerous to deal with acid, yet etching done with acid is very attractive as compared to using other chemicals.

10.2 pH SCALE

Concentration of hydrogen ion $[H^+]$ in pure water is the basis for the pH scale. Water is a weak electrolyte because it ionizes very slightly into ions in a process called **auto-ionization** or self-ionization;

$$H_2O \rightleftharpoons H^+ + OH^-$$

The equilibrium expression of this reaction may be written as

$$K_c = \frac{[H^+][OH^-]}{[H_2O]}$$

As concentration of water (H_2O) is almost constant. The above equation may be written as

$$K_c[H_2O] = [H^+][OH^-]$$

A new equilibrium constant known as ionic product constant of water 'K_w' is used instead of product of equilibrium constant and $[H_2O]$. Therefore,

$$K_w = [H^+][OH^-] = 1.0 \times 10^{-14} \text{ at } 25°C$$

As we know, one molecule of water produces one H^+ ion and one OH^- ion on dissociation so

$$[H^+] = [OH^-] \quad \text{Or} \quad [H^+]^2 = 1.0 \times 10^{-14}$$

$$[H^+] = \sqrt{1.0 \times 10^{-14}}$$

Therefore, $[H^+] = 1.0 \times 10^{-7}$ M at 25°C

As it is difficult to deal with such small figures having negative exponents, so it is convenient *to convert these figures into a positive figure using a numerical system.* It is taking the common (base-10) logarithm of the figure and multiplying it with -1. 'p' before a symbol means' negative logarithm of the symbol. So 'p' before H means negative logarithm of H^+. Therefore, ***pH** is the negative logarithm of molar concentration of the hydrogen ions. That is,*

$$pH = -\log [H^+]$$

With reference to this equation, a scale develops according to the molar concentration of H^+ ions that is called pH scale. It ranges from **0 to 14**. According to this scale, pH of water is calculated as:

$$pH = -\log [H^+]$$

$$pH = -\log (1.0 \times 10^{-7}) = 7$$

Similarly $$pOH = -\log [OH^-]$$

$$pOH = -\log (1.0 \times 10^{-7}) = 7$$

pH value normally varies from 0 to 14. Therefore:

$$pH + pOH = 14$$

So, the sum of the pH and pOH of the solution is always 14 at 25 °C. Such as;

	Highly acidic			Slightly acidic			neutral		Slightly basic				Highly basic	
pH	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
pOH	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

A solution of a compound of pH 7 or pOH 7 is considered a neutral solution. Solutions of pH less than 7 are acidic and more than 7 are basic as are also shown in figure 10.1.

		$[H^+]$	pH	$[OH^-]$	pOH
More basic		1×10^{-14}	14.0	1×10^{0}	0.0
		1×10^{-13}	13.0	1×10^{-1}	1.0
		1×10^{-12}	12.0	1×10^{-2}	2.0
	BASIC	1×10^{-11}	11.0	1×10^{-3}	3.0
		1×10^{-10}	10.0	1×10^{-4}	4.0
		1×10^{-9}	9.0	1×10^{-5}	5.0
		1×10^{-8}	8.0	1×10^{-6}	6.0
	NEUTRAL	1×10^{-7}	7.0	1×10^{-7}	7.0
More acidic		1×10^{-6}	6.0	1×10^{-8}	8.0
		1×10^{-5}	5.0	1×10^{-9}	9.0
		1×10^{-4}	4.0	1×10^{-10}	10.0
	ACIDIC	1×10^{-3}	3.0	1×10^{-11}	11.0
		1×10^{-2}	2.0	1×10^{-12}	12.0
		1×10^{-1}	1.0	1×10^{-13}	13.0
		1×10^{0}	0.0	1×10^{-14}	14.0

Fig. 10.1 pH scale showing relation among $[H^+]$ and pH & pOH sacle showing relation among $[OH^-]$ and pOH

Since the pH scale is logarithmic, a solution of pH 1 has 10 times higher concentration of $[H^+]$ than that of a solution of pH 2; 100 times than that of a solution of pH 3 and so on. Hence, low pH value means strong acid while high pH value means a strong base and vice versa.

Conclusion

(i) pH of a neutral solution is always 7.

(ii) Acidic solutions have pH less than 7.

(iii) Basic solutions have pH value greater than 7.

(iv) pH and pOH values range from 0 to 14.

Uses of pH

(i) It is used to determine acidic or basic nature of a solution.

(ii) It is used to produce medicines, culture at a microbiological particular concentration of H^+ ion.

(iii) It is used to prepare solutions of required concentrations necessary for certain biological reactions.

10.2.1 Indicators

Indicators are the organic compounds. They have different colours in acidic and alkaline solutions. Litmus is a common indicator. It is red in acidic solutions and blue in alkaline solutions.

Each indicator has a specific colour in acidic medium which changes at a specific pH to another colour in basic medium. For example, phenolphthalein is colourless in strongly acidic solution and red in strongly alkaline solution. It changes colour at a pH of about 9. This means phenolphthalein is colourless in a solution with pH less than 9. If the pH is above 9, phenolphthalein is red as is shown in figure 10.2.

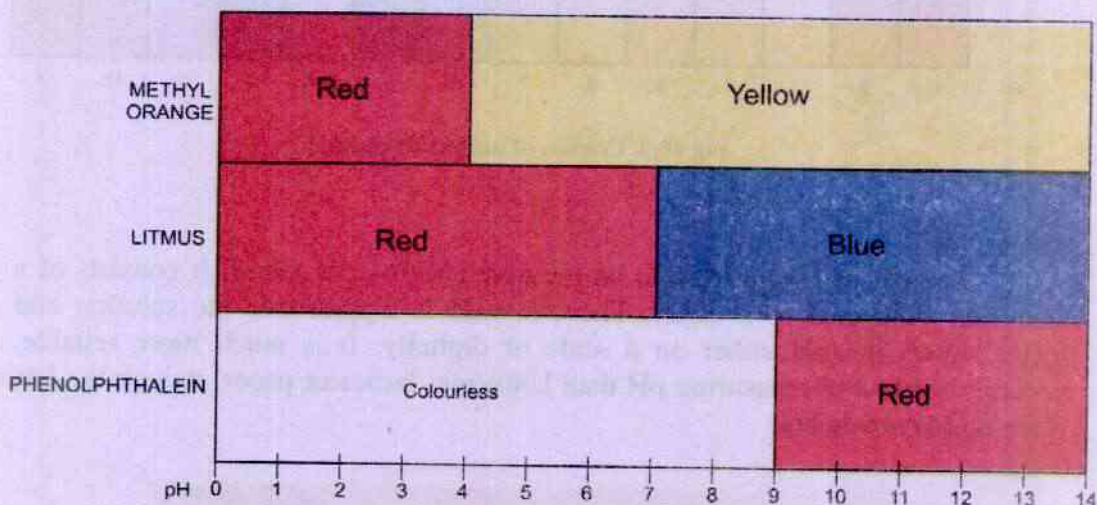



Fig. 10.2. Colours of indicators at different pH solutions

A few commonly used indicators in titrations are given in Table 10.3

Table 10.3. Few important indicators

Indicator	Colour in strongly acidic solution	pH at which colour changes	Colour in strongly alkaline solution
Methyl orange	red	4	yellow
Litmus	red	7	blue
Phenolphthalein	colourless	9	red

Measuring pH of a Solution

(i) Universal Indicator

Some indicators are used as mixtures. The mixture indicator give different colours at different pH values. Hence, it is used to measure the pH of a solution. Such a mixed indicator is called Universal Indicator or simply pH indicator. The pH of solution can be measured by dipping a piece of Universal Indicator paper in the solution. The pH is then found by comparing the colour obtained with a colour chart as shown in figure 10.3.

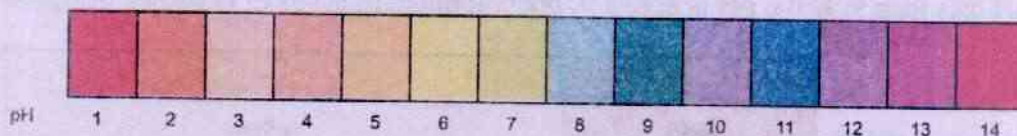
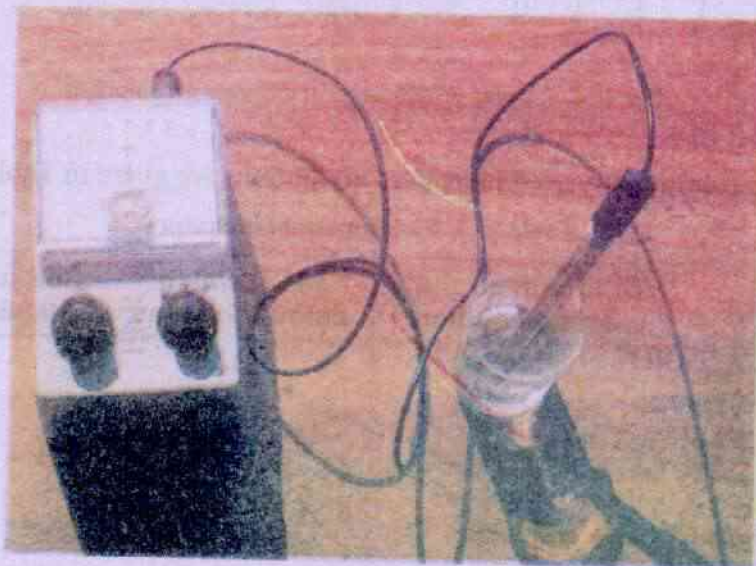



Fig.10.3. Colours of universal indicator

(ii) The pH Meter

The pH of a solution can be measured with a pH meter. It consists of a pH electrode connected to a meter. The electrode is dipped into the solution and the meter shows the pH either on a scale or digitally. It is much more reliable and accurate method of measuring pH than Universal Indicator paper, though the latter is often more convenient.

pH meter

Problem 10.2

A solution of hydrochloric acid is 0.01M. What is its pH value?

Solution Hydrochloric acid is a strong acid so it ionizes completely. That is:

$$HCl_{(aq)} \longrightarrow H^+_{(aq)} + Cl^-_{(aq)}$$

So, its solution also contains 0.01M H^+ ions, i.e., 10^{-2} M.

$$pH = -\log [H^+]$$

By putting the values of H^+ ions in the above equation:

$$pH = -\log 10^{-2}$$

$$pH = 2$$

Problem 10.3

Find out the pH and pOH of 0.001M solution of KOH?

Solution Potassium hydroxide solution is a strong base. It ionizes completely such that one mole of KOH gives one mole of OH^- ions.

$$KOH_{(aq)} \longrightarrow K^+_{(aq)} + OH^-_{(aq)}$$

Therefore, 0.001M solution of KOH produces 0.001M OH^- ions.

$$[OH^-] = 0.001\ M \quad \text{or} \quad 10^{-3}\ M$$

$$pOH = -\log 10^{-3} = 3$$

$$pH = 14 - 3 = 11$$

Problem 10.4

Find the pH of 0.01M sulphuric acid?

Solution: Sulphuric acid is a strong dibasic acid. It ionizes completely and its one mole produces 2 moles of hydrogen ions as presented in equation.

$$H_2SO_{4(aq)} \longrightarrow 2H^+_{(aq)} + SO_4^{2-}{}_{(aq)}$$

Therefore, 0.01M sulphuric acid will produce 2 x 0.01M hydrogen ions.

Hence, hydrogen ions concentration is

$$[H^+] = 2 \times 10^{-2}\ M$$

$$pH = -\log(2 \times 10^{-2}) = -(\log 2 + \log 10^{-2})$$

$$pH = -\log 2 - \log 10^{-2} \qquad \text{as } -\log 10^{-2} = 2$$

$$pH = 2 - \log 2 \qquad pH = 2 - 0.3 = 1.7$$

i. Why pure water is not a strong electrolyte?

ii. HCl and H_2SO_4 are strong acids. While their solutions are equimolar, they have different pH value as calculated in problem 10.2 and 10.4. Why they have different pH values?

iii. Why ionic-product constant of water is temperature dependent?

iv. Differentiate between 'p' and pH.

Areas of work for analytical chemists.

Analytical chemist examine substances qualitatively and quantitatively. They identify substances and evaluate their properties.

They have a wide area for working ranging from basic research in laboratories to analytical research in industries. They work in almost all industries including manufacturing, pharmaceuticals, healthcare, forensics and public protection - where they test air, water, industrial waste, drugs and food to make sure they are safe. They ensure the quality of the products in industry.

10.3 SALTS

***Salts** are ionic compounds generally formed by the neutralization of an acid with a base.*

Salts are made up of positive ions (cations) and negative ions (anions). A cation is metallic ion derived from a base, therefore, it is called basic radical. While anion is derived from an acid therefore it is called acid radical.

A salt gets its name from the names of the metal and the acid as shown in Table 10.4.

Table 10.4 Acids and their Salts

Metal	Acid	Salt name
Sodium (Na)	Hydrochloric acid (HCl)	Sodium chloride (NaCl)
Potassium (K)	Nitric acid (HNO_3)	Potassium nitrate (KNO_3)
Zinc (Zn)	Sulphuric acid (H_2SO_4)	Zinc sulphate ($ZnSO_4$)
Calcium (Ca)	Phosphoric acid (H_3PO_4)	Calcium phosphate $Ca_3(PO_4)_2$
Silver (Ag)	Acetic acid (CH_3COOH)	Silver acetate (CH_3COOAg)

Characteristic properties of salts

(i) Salts are ionic compounds found in crystalline form.

(ii) They have high melting and boiling points.

(iii) Most of the salts contain water of crystallization which is responsible for the shape of the crystals. Number of molecules of water are specific for each salt and they are written with the chemical formula of a salt. For example,

Copper sulphate $CuSO_4.5H_2O$; Calcium sulphate $CaSO_4.2H_2O$

(iv) Salts are neutral compounds. Although, they do not compose of equal number of positive and negative ions, but have equal number of positive and negative charges.

10.3.1 Preparation

Salts may be water soluble or insoluble. The methods used for the preparation of salts are based on their solubility in water.

General Methods for the Preparation of Salts

There are five general methods for the preparation of salts. Four methods make soluble salts but one prepares insoluble salts.

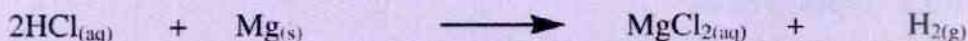
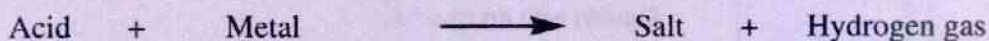
(i) Preparation of soluble salts

Soluble salts are often prepared in water. Therefore, they are recovered by evaporation or crystallization.

(a) By the reaction of an acid and a metal: (Direct Displacement method)

This is direct displacement method in which hydrogen ion of acid is replaced by a reactive metal. Such as calcium, magnesium, zinc and iron, e.g.

$$\text{Acid} + \text{Metal} \longrightarrow \text{Salt} + \text{Hydrogen gas}$$

$$2HCl_{(aq)} + Mg_{(s)} \longrightarrow MgCl_{2(aq)} + H_{2(g)}$$

(b) By the reaction of an acid and a base: (Neutralization method)

It is a neutralization reaction in which acid and base react to produce a salt and water.

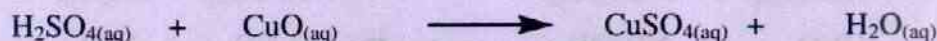
$$\text{Acid} + \text{Base} \longrightarrow \text{Salt} + \text{Water}$$

$$HCl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$$

(c) By the reaction of an acid and metallic oxide:

Mostly the insoluble metallic oxides react with dilute acids to form salt and water.

$$\text{Acid} + \text{Metallic oxide} \longrightarrow \text{Salt} + \text{Water}$$

$$H_2SO_{4(aq)} + CuO_{(aq)} \longrightarrow CuSO_{4(aq)} + H_2O_{(aq)}$$

(d) **By the reaction of an acid and a carbonate:**

Dilute acids react with metallic carbonates to produce salts, water and carbon dioxide gas.

$$2HNO_{3(aq)} + Na_2CO_{3(aq)} \longrightarrow 2NaNO_{3(aq)} + H_2O_{(l)} + CO_{2(g)}$$

(ii) **Preparation of insoluble salts**

In this method, usually solutions of soluble salts are mixed. During the reaction exchange of ionic radicals (i.e., metallic radicals exchange with acidic radicals) takes place to produce two new salts. One of the salts is insoluble and the other is soluble. The insoluble salt precipitates (solidify in solution).

$$AgNO_{3(aq)} + NaCl_{(aq)} \longrightarrow AgCl_{(s)} + NaNO_{3(aq)}$$

$$Na_2CO_{3(aq)} + CuSO_{4(aq)} \longrightarrow CuCO_{3(s)} + Na_2SO_{4(aq)}$$

Test yourself 10.4

i. How are the salts named?

ii. Name the salts which are formed when Zn metal reacts with following acids.
a. nitric acid b. phosphoric acid c. acetic acid

iii. How will you justify salts are neutral compounds?

iv. How many water of crystallizations are present in $CuSO_4.5H_2O$ and $CaSO_4.2H_2O$?

v. Name the type of reaction that takes place between an acid and a metal. Which gas would evolve in the reaction? Explain with an example.

10.3.2 Types of Salts

Following are the main classes of salts.

(i) Normal salts
(ii) Acidic salts
(iii) Basic salt
(iv) Double salts
(v) Mixed salts
(vi) Complex salts

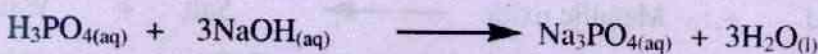
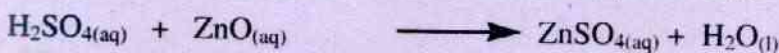
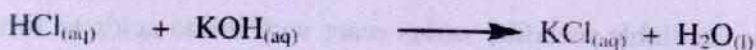
(i) **Normal or Neutral Salts**

A salt formed by the total replacement of ionizable H^+ ions of an acid by a positive metal ion or NH_4^+ ions is called normal or neutral salt. These salts are neutral to litmus, that is,

$$HCl_{(aq)} + KOH_{(aq)} \longrightarrow KCl_{(aq)} + H_2O_{(l)}$$

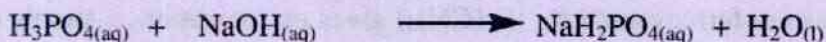
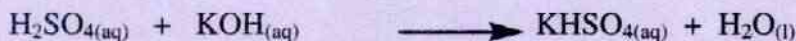
$$H_2SO_{4(aq)} + ZnO_{(aq)} \longrightarrow ZnSO_{4(aq)} + H_2O_{(l)}$$

$$H_3PO_{4(aq)} + 3NaOH_{(aq)} \longrightarrow Na_3PO_{4(aq)} + 3H_2O_{(l)}$$

$$HNO_{3(aq)} + NH_4OH_{(aq)} \longrightarrow NH_4NO_{3(aq)} + H_2O_{(l)}$$

(ii) **Acidic Salts**

These salts are formed by partial replacement of a replaceable H^+ ions of an acid by a positive metal ion.

$$H_2SO_{4(aq)} + KOH_{(aq)} \longrightarrow KHSO_{4(aq)} + H_2O_{(l)}$$

$$H_3PO_{4(aq)} + NaOH_{(aq)} \longrightarrow NaH_2PO_{4(aq)} + H_2O_{(l)}$$

These salts turn blue litmus red.

Acidic salts react with bases to form normal salts.

$$KHSO_{4(aq)} + KOH_{(aq)} \longrightarrow K_2SO_{4(aq)} + H_2O_{(l)}$$

$$NaH_2PO_{4(aq)} + 2NaOH_{(aq)} \longrightarrow Na_3PO_{4(aq)} + 2H_2O_{(l)}$$

(iii) **Basic Salts**

Basic salts are formed by the incomplete neutralization of a polyhydroxy base by an acid.

$$Al(OH)_{3(aq)} + HCl_{(aq)} \longrightarrow Al(OH)_2Cl_{(aq)} + H_2O_{(l)}$$

$$Pb(OH)_{2(aq)} + CH_3COOH_{(aq)} \longrightarrow Pb(OH)CH_3COO_{(aq)} + H_2O_{(l)}$$

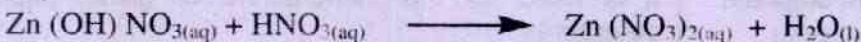
$$Zn(OH)_{2(aq)} + HNO_{3(aq)} \longrightarrow Zn(OH)NO_{3(aq)} + H_2O_{(l)}$$

These salts further react with acids to form normal salts.

$$Al(OH)_2Cl_{(aq)} + HCl_{(aq)} \longrightarrow Al(OH)Cl_{2(aq)} + H_2O_{(l)}$$

$$Al(OH)Cl_{2(aq)} + HCl_{(aq)} \longrightarrow AlCl_{3(aq)} + H_2O_{(l)}$$

$$Pb(OH)CH_3COO + CH_3COOH_{(aq)} \longrightarrow Pb(CH_3COO)_{2(aq)} + H_2O_{(l)}$$

$$Zn(OH)NO_{3(aq)} + HNO_{3(aq)} \longrightarrow Zn(NO_3)_{2(aq)} + H_2O_{(l)}$$

(iv) **Double Salts**

Double salts are formed by two normal salts when they are crystallized from a mixture of equimolar saturated solutions. The individual salt components retain their properties. The anions and cations give their respective tests. Mohr's salt $FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$; Potash alum $K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$; Ferric alum $K_2SO_4 \cdot Fe_2(SO_4)_3 \cdot 24H_2O$, are examples of double salts.

Mixed salts contain more than one basic or acid radicals. Bleaching powder Ca(OCl) Cl, is an example of mixed salts.

(vi) Complex Salts

Complex salts on dissociation provides a simple cation and a complex anion or vice versa. Only the simple ions yields the characteristics test for cation or anion. For example:

Potassium ferrocyanide $K_4[Fe(CN)_6)$ gives on ionization, a simple cation K^+ and complex anion $[Fe(CN)_6]^{-4}$.

10.3.3 Uses of Salts

Salts have vast applications in industries and in our daily life. Some common salts and their uses are given in Table 10.5;

Table 10.5 Uses of Salts

Name of salts	Common and Industrial Uses
Sodium chloride ($NaCl$)	It is commonly used as a table salt and for cooking purposes. It is also used for de-icing roads in winter and for the manufacture of sodium metal, caustic soda, washing soda.
Sodium carbonate (Na_2CO_3) Soda ash	It is used for the manufacture of glass, detergents, pulp and paper and other chemicals.
Sodium carbonate ($Na_2CO_3.10H_2O$) Washing soda	It is used as cleaning agent for domestic and commercial purposes, for softening of water, in manufacture of chemicals like caustic soda ($NaOH$), borax, glass, soap and paper.
Sodium sulphate (Na_2SO_4)	It is used for the manufacture of glass, paper and detergents
Sodium silicate (Na_2SiO_3)	It is used for the manufacture of detergents, cleaning agents and adhesives.
Sodium chlorate ($NaClO_3$)	It is used for manufacture of explosives, plastics and other chemicals.
Sodium tetraborate ($Na_2B_4O_7.10H_2O$)	It is used for manufacture of heat resistance glass (pyrex), glazes and enamels, in leather industry for soaking and cleaning hides.

Calcium chloride ($CaCl_2$)	It is used for de-icing roads in winter, as a drying agent of chemical reagents.and as freezing agent.
Calcium oxide (CaO) Quick lime	It is used as drying agent for gases and alcohol and in steel making, water treatment and other chemicals like slaked lime, bleaching powder, calcium carbide. For purification of sugar, a mixture of CaO and NaOH called soda lime is used to remove carbon dioxide and water vapours from air.
Calcium sulphate ($CaSO_4.2H_2O$)	Gypsum is used as fertilizer, to prepare plaster of Paris which is used for making statues, casts, etc.
Potassium Nitrate (KNO_3)	It is used as fertilizer and for the manufacture of flint glass.

Neutralization Reaction

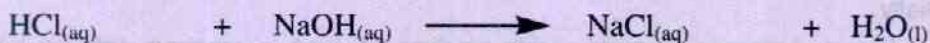
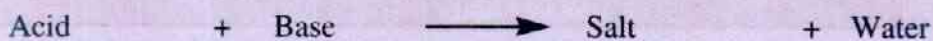
A reaction between an acid and a base is called a neutralization reaction. It produces a salt and water. A few balanced chemical reactions are given here:

$$\text{Acid} + \text{Base} \longrightarrow \text{Salt} + \text{Water}$$

$$HCl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$$

$$H_2SO_{4(aq)} + 2NaOH_{(aq)} \longrightarrow Na_2SO_{4(aq)} + 2H_2O_{(l)}$$

$$CH_3COOH_{(aq)} + NaOH_{(aq)} \longrightarrow CH_3COONa_{(aq)} + H_2O_{(l)}$$

Test yourself 10.5

i. Name the types of salts.

ii. H_3PO_4 is a weak acid but its salt (Na_3PO_4) with strong base NaOH is neutral. Explain it.

iii. How the basic salts turns into normal salts? Explain with an example.

iv. What are complex salts.

v. Na_2SO_4 is a neutral salt What are its uses?

Interesting Information

Your tears perspiration and blood taste salty not because of you eat common salt every day rather your body contains other salts that give salty taste to your tears, perspiration and blood.

Preservatives in food

Chemicals used to prevent food spoilage are called preservatives. Food spoiling may be due to microbial actions or chemical reactions. So preservatives serve as either anti-microbial or anti-oxidants or both.

Manufacturers add preservatives mostly to prevent spoiling during transportation and storage of foods for a period of time.

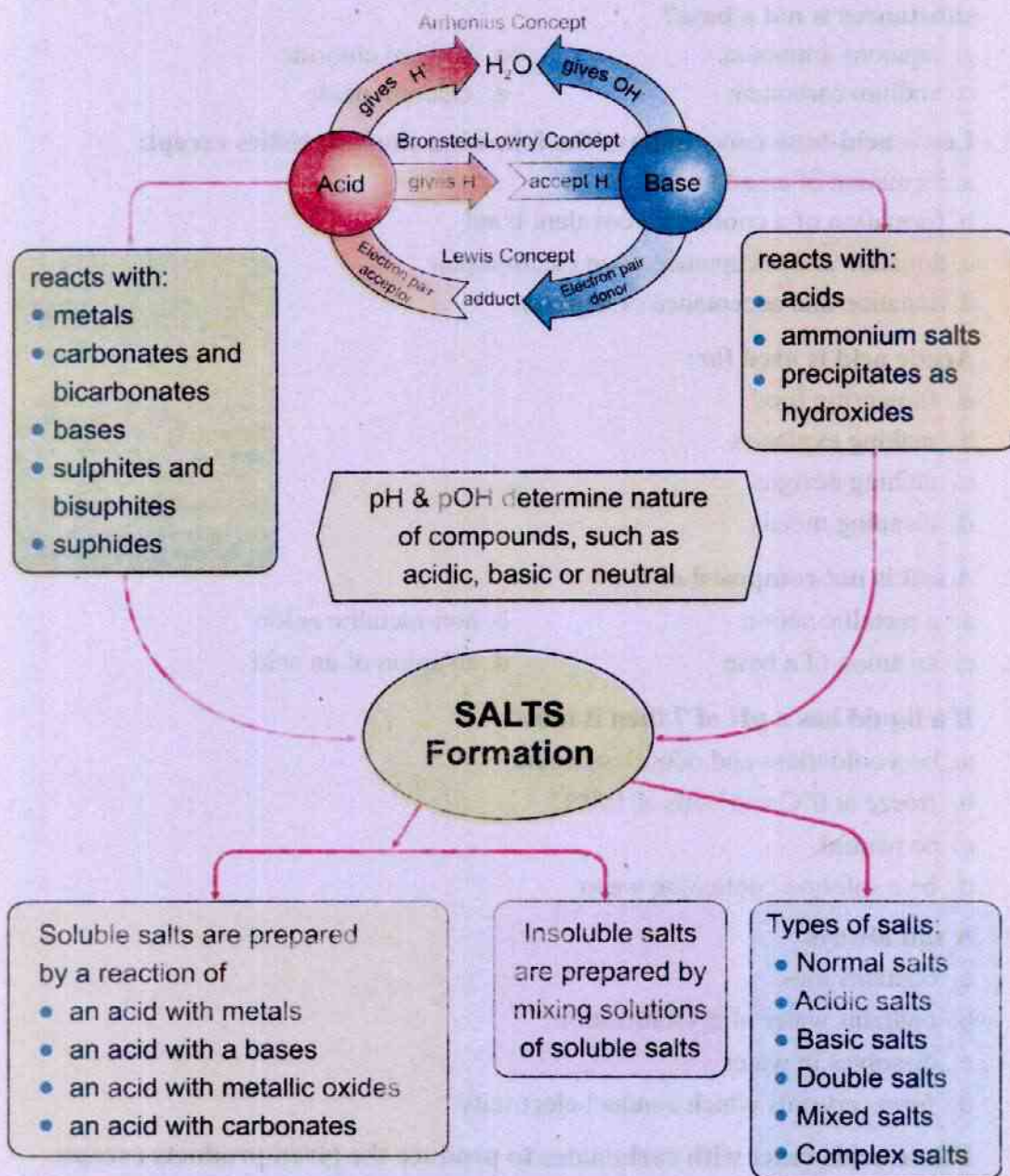
Natural food preservatives are salts, sugar, alcohol, vinegar, etc. They efficiently control the growth of bacteria in food. They are used to preserve meat, fish, etc.

Acid Rain

Acid rain is formed by dissolving acidic air pollutants like oxides of sulphur and nitrogen by rain water. As a result pH of the rain water decreases, i.e., it becomes acidic.When this acid rain falls down, it damages animals, plants, buildings, water bodies and even soil.

Key Points

- Strong acids or bases ionize completely in water while weak acids and bases ionize partially.
- According to Arrhenius concept, acids produce H^+ ions in aqueous solution while bases produce OH^- ions in aqueous solution.
- According to Bronsted-Lowry concept, acid are proton donor and bases are proton acceptor, so this concept is applicable to non-aqueous solutions.
- A substance that can behave as an acid as well as base depending upon the nature of other substances is called amphoteric.
- According to Lewis concept; acids are electron pair acceptors and bases are electron pair donors.
- The product of any Lewis acid base reaction is a single specie called adduct.
- "p" scale is the conversion of very small figures into positive figures by taking the common logarithm of the small figure and multiplying it with-1.
- pH scale is the negative logarithm of concentration of hydrogen ions.
- A substance having pH less than 7 is acidic while a substance having pH more than 7 is basic. A substance of pH 7 is called neutral.
- Salts are ionic compounds made up of metallic cation and non-metallic anion.
- Different methods for the preparation of soluble and insoluble salts have been discussed.
- Normal salts are made up of cations of strong bases and anions of strong acids.
- Acidic salts are made up of cations of weak bases and anions of strong acids.

CONCEPT DIAGRAM

EXERCISE

Multiple Choice Questions

Put a (✓)on the correct answer

1. **A base is a substance which neutralizes an acid. Which of these substances is not a base?**
   a. aqueous ammonia
   b. sodium chloride
   c. sodium carbonate
   d. calcium oxide

2. **Lewis acid-base concept have the following characteristics except:**
   a. formation of an adduct
   b. formation of a coordinate covalent bond
   c. donation and acceptance of an electron pair
   d. donation and acceptance of a proton

3. **Acetic acid is used for:**
   a. flavouring food
   b. making explosive
   c. etching designs
   d. cleaning metals

4. **A salt is not composed of :**
   a. a metallic cation
   b. non-metallic anion
   c. an anion of a base
   d. an anion of an acid

5. **If a liquid has a pH of 7 then it must:**
   a. be a colourless and odourless liquid
   b. freeze at 0°C and boils at 100°C
   c. be neutral
   d. be a solution containing water

6. **A salt always :**
   a. contains ions
   b. contains water of crystallization
   c. dissolves in water
   d. forms crystals which conduct electricity

7. **Dilute acids react with carbonates to produce the given products except:**
   a. salt
   b. water
   c. carbon dioxide
   d. hydrogen

8. **In the preparation of insoluble salts, which one of the facts is incorrect?**
   a. two soluble salts are mixed
   b. two soluble salts are produced
   c. one of the salts produced is insoluble
   d. both of the salts produced are insoluble

9. **A reaction between an acid and a base produces**
   a. salt and water b. salt and gas
   c. salt and an acid d. salt and a base

10. **The conjugate acid of HPO_4^{2-} is :**
   a. PO_4^{3-} b. $H_2PO_4^{2-}$
   c. $H_2PO_4^{-}$ d. H_3PO_4

11. **What is the pOH of a 0.02M $Ca(OH)_2$?**
   a. 1.698 b. 1.397
   c. 12.31 d. 12.61

12. **Which one of the following species is not amphoteric?**
   a. H_2O b. NH_3
   c. HCO_3^- d. SO_4^{2-}

13. **The product of Lewis acid-base reaction is called adduct. The bond between the adduct specie is:**
   a. ionic b. covalent
   c. metallic d. coordinate covalent

14. **The water of crystallization is responsible for the**
   a. melting points of crystals b. boiling points of crystals
   c. shapes of crystals d. transition point of crystals

15. **You want to dry a gas which one of the following salt you will use.**
   a. $CaCl_2$ b. NaCl
   c. CaO d. Na_2SiO_3

16. **Ferric hydroxide ($Fe(OH)_3$) is precipitated out of solution when aqueous sodium hydroxide solution is added to ferric chloride ($FeCl_3$)**

$$FeCl_{3(aq)} + 3NaOH_{(aq)} \longrightarrow Fe(OH)_{3(s)} + 3NaCl_{(aq)}$$

   Colour of the precipitate is:
   a. white b. blue
   c. dirty green d. brown

17. Which ion is the conjugate base of sulphuric acid?

a. SO_3^{2-} b. S^{2-}

c. HSO_3^- d. HSO_4^-

18. Which one of the following is a Lewis base?

a. NH_3 b. BF_3

c. H^+ d. $AlCl_3$

19. According to the Lewis concept, acid is a substance which can

a. donate a proton b. donate a pair of electron

c. accept a proton d. accept a pair of electron

20. Given $K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$ at 25 °C
What is the concentration of H^+ in pure water at 25°C?

a. 1×10^{-7} mol dm^{-3} b. 1×10^{7} mol dm^{-3}

c. 1×10^{-14} mol dm^{-3} d. 1×10^{14} mol dm^{-3}

Short Questions:

1. Name three common household substances having
   a. pH value greater than 7
   b. pH value less than 7
   c. pH value equal to 7
2. Define a base and explain all alkalies are bases, but all bases are not alkalies.
3. Define Bronsted-Lowry base and explain with an example that water is a Bronsted-Lowry base.
4. How can you justify that Bronsted-Lowry concept of acid and base is applicable to non-aqueous solutions?
5. Which kind of bond forms between Lewis acid and a base?
6. Why H^+ ion acts as a Lewis acid?
7. Name two acids used in the manufacture of fertilizers.
8. Define pH. What is the pH of pure water?
9. How many times a solution of pH 1 will be stronger than that of a solution having pH 2?
10. Define the followings:

    i. Normal salt ii. Basic salt

11. Na_2SO_4 is a neutral salt while $NaHSO_4$ an acidic salt. Justify.
12. Give a few characteristic properties of salts.
13. How are the soluble salts recovered from water?
14. How are the insoluble salts prepared?
15. Why a salt is neutral, explain with an example?
16. Name an acid used in the preservation of food.
17. Name the acids present in:
    i. Vinegar
    ii. Ant sting
    iii. Citrus fruit
    iv. Sour milk
18. How can you justify that $Pb(OH)NO_3$ is a basic salt?
19. You are in a need of an acidic salt. How can you prepare it?
20. Which salt is used to prepare plaster of Paris?

Extensive Questions:

1. Define an acid and a base according to Bronsted-Lowry concept and justify with examples that water is an amphoteric compound.
2. Explain the Lewis concept of acids and bases.
3. What is auto-ionization of water? How is it used to establish the pH of water?
4. Define a salt and give the characteristic properties of salts.
5. Explain with examples that how soluble salts are prepared?
6. Give the characteristics of an acidic salt.
7. Give four uses of calcium oxide.
8. You are having a strong acid (HNO_3) and strong base (NaOH) on mixing
    i. What type of salt you will have?
    ii. What type of this reaction will be?
    iii. Will it be soluble or insoluble?
    iv. If it is soluble, how it will be recovered?
9. Explain why:
    i. HCl forms only one series of salts.
    ii. H_2SO_4 forms two series of salts.
    iii. H_3PO_4 form three series of salts.

    Give necessary equations.

10. Classify the following salts as soluble or insoluble salts:
    - i. Sodium chloride
    - ii. Silver nitrate
    - iii. Lead chloride
    - iv. Copper sulphate
    - v. Barium sulphate
    - vi. Ammonium chloride
    - vii. Sodium carbonate
    - viii. Calcium carbonate
    - ix. Ferric chloride
    - x. Magnesium sulphate
11. Complete and balance the following equations:
    - i. Aluminium + Hydrochloride acid $\longrightarrow$
    - ii. Copper oxide + Sulphuric acid $\longrightarrow$
    - iii. Iron sulphide + Sulphuric acid $\longrightarrow$
    - iv. Ammonium chloride + Sodium hydroxide $\longrightarrow$
    - v. Ferric chloride + Sodium hydroxide $\longrightarrow$

Numericals:

1. Calculate the pH and pOH of 0.2 M H_2SO_4?
2. Calculate the pH of 0.1 M KOH?
3. Calculate the pOH of 0.004 M HNO_3?
4. Complete the following Table.

Solution	$[H^+]$	$[OH^-]$	pH	pOH
(i) 0.15 M HI	—	—	—	—
(ii) 0.040 M KOH	—	—	—	—
(iii) 0.020 M $Ba(OH)_2$	—	—	—	—
(iv) 0.00030 M $HClO_4$	—	—	—	—
(v) 0.55 M NaOH	—	—	—	—
(vi) 0.055 M HCl	—	—	—	—
(vii) 0.055 M $Ca(OH)_2$	—	—	—	—

Chapter 11

Organic Chemistry

Major Concepts

Time allocation

Teaching periods	10
Assessment periods	03
Weightage	5%

Students Learning Outcomes

Student will be able to:

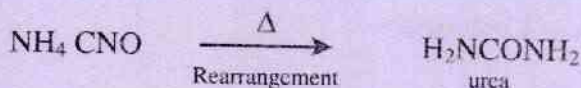
- recognize structural, condensed, and molecular formulae of the straight chain hydrocarbons up to ten carbon atoms. (Understanding);
- identify some general characteristics of organic compounds; (Remembering);
- explain the diversity and magnitude of organic compounds. (Understanding);
- list some sources of organic compounds (Applying)
- list the uses of organic compounds (Remembering)
- recognize and identify a molecule`s functional groups. (Understanding)
- convert alkanes into alkyl radicals. (Applying)
- differentiate between alkanes and alkyl radicals. (Analyzing)
- define functional group. (Remembering)
- differentiate between organic compounds on the basis of their functional groups. (Analyzing)
- classify organic compounds into straight chain, branched chain and cyclic compounds. (Understanding)

Introduction:

Initially (before 1828), the name organic chemistry was given for the chemistry of compounds obtained from plants and animals, i.e., from living organism. The word organic signifies life. Lavoisier showed that compounds obtained from plants were often made of C, H and O elements while compounds obtained from animals contain elements C, H, N, O, S, P.... etc.

In early 19th century, Swedish chemist Jacob Berzellius put forward the "Vital Force Theory". According to this theory organic compounds could not be prepared in laboratories because they were supposed to be synthesized under the influence of a mysterious force called Vital Force, inherent only in living things.

The Vital Force theory suffered death blow in 1828 when Wohler synthesized the first organic compound urea from inorganic substance by heating ammonium cyanate (NH_4CNO):

$$NH_4\,CNO \xrightarrow[\text{Rearrangement}]{\Delta} \underset{\text{urea}}{H_2NCONH_2}$$

Later on Vital Force theory was further negated by Kolbe (1845) when he prepared acetic acid in laboratory.

Organic compounds include carbohydrates, proteins, lipids, enzymes, vitamins, drugs, pharmaceutical products, fertilizers, pesticides, paints, dyes, synthetic rubbers, plastics, artificial fibres and many polymers, etc.

11.1 ORGANIC COMPOUNDS

Today, there are about ten millions of organic compounds and thousands of new organic compounds are being prepared every year. Therefore, the old definition has been rejected.

A detailed investigation of organic compounds revealed that all of them contain covalently bonded carbon and hydrogen as their essential constituent. Hence, *organic compounds are hydrocarbons (compounds of carbon and hydrogen) and their derivatives, in which covalently bonded carbon is an essential constituent.*

The branch of chemistry which deals with the study of hydrocarbons and their derivatives is known as **organic chemistry.**

Though the oxides of carbon like carbon monoxide and carbon dioxide, carbonates, bicarbonates and carbides are also carbon compounds, they are not treated as organic compounds because their properties are quite different from those of organic compounds. Each organic compound has specific formula.

There are four types of formulae of organic compounds:

(i) Molecular formula
(ii) Structural formula
(iii) Condensed formula
(iv) Dot and cross formula

Interesting Information

Naphthalene is an organic compound. It sublimes at room temperature giving out very strong smell. It is used in moth balls to keep insects away from clothes.

(i) Molecular Formula

The formula which represents the actual number of atoms in one molecule of the organic compound is called the molecular formula, e.g., molecular formula of butane is C_4H_{10}. It shows:

(a) Butane is made up of carbon and hydrogen atoms.

(b) Each molecule of butane consists of 4 carbon atoms and 10 hydrogen atoms.

(ii) Structural Formula

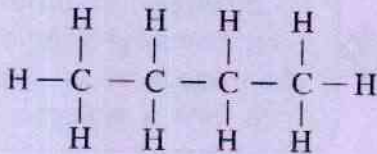
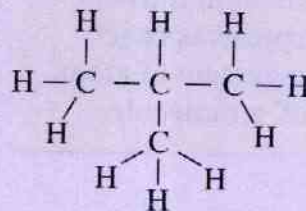
Structural formula of a compound represents the exact arrangement of the different atoms of various elements present in a molecule of a substance.

In a structural formula, single bond is represented by a single line (–), a double bond by two lines (=) and a triple bond by three lines (≡) between the bonded atoms.

Organic compounds may have same molecular formulae but different structural formulae, e.g., structural formulae of butane C_4H_{10} are:

```
    H   H   H   H
    |   |   |   |
H — C — C — C — C — H
    |   |   |   |
    H   H   H   H
```

n-Butane

```
    H   H   H
    |   |   |
H — C — C — C — H
   /    |    \
  H     C     H
      / | \
     H  |  H
        H
```

isobutane

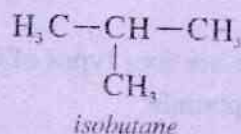
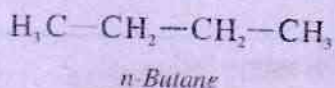
(iii) Condensed Formula

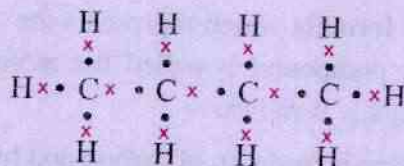
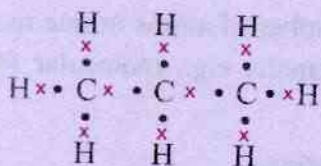
The formula that indicates the group of atoms joined together to each carbon atom in a straight chain or a branched chain is called the condensed formula.

$$H_3C-CH_2-CH_2-CH_3$$

n-Butane

$$H_3C-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH_3$$

isobutane

(iv) Electronic or Dot and Cross Formula

The formula which shows the sharing of electrons between various atoms in one molecule of the organic compound is called dot and cross formula or electronic formula.

Summary of the formulae of organic compounds is reproduced as;

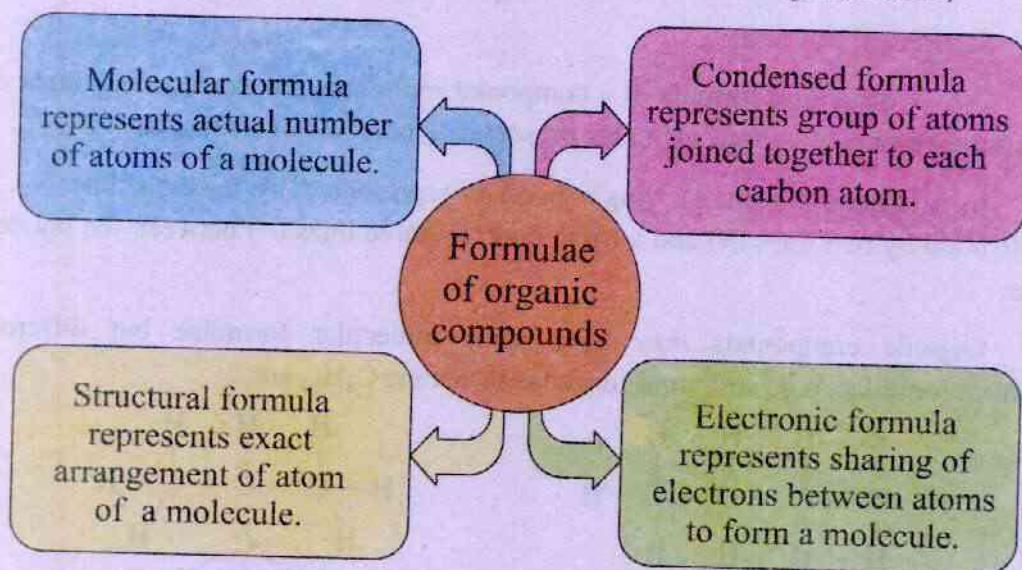



Table 11.1 presents the names, molecular, condensed and structural formulae of the first ten hydrocarbons.

Table 11.1 Names, Molecular, Condensed and Structural Formulae of Hydrocarbons

Name	Molecular Formula	Condensed Form	Structural Form
Methane	CH_4	CH_4	H H–C–H H
Ethane	C_2H_6	H_3CCH_3	H H H–C–C–H H H
Propane	C_3H_8	$H_3CCH_2CH_3$	H H H H–C–C–C–H H H H
Butane	C_4H_{10}	$H_3C(CH_2)_2CH_3$	H H H H H–C–C–C–C–H H H H H
Pentane	C_5H_{12}	$H_3C(CH_2)_3CH_3$	H H H H H H–C–C–C–C–C–H H H H H H
Hexane	C_6H_{14}	$H_3C(CH_2)_4CH_3$	H H H H H H H–C–C–C–C–C–C–H H H H H H H
Heptane	C_7H_{16}	$H_3C(CH_2)_5CH_3$	H H H H H H H H–C–C–C–C–C–C–C–H H H H H H H H
Octane	C_8H_{18}	$H_3C(CH_2)_6CH_3$	H H H H H H H H H–C–C–C–C–C–C–C–C–H H H H H H H H H
Nonane	C_9H_{20}	$H_3C(CH_2)_7CH_3$	H H H H H H H H H H–C–C–C–C–C–C–C–C–C–H H H H H H H H H H
Decane	$C_{10}H_{22}$	$H_3C(CH_2)_8CH_3$	H H H H H H H H H H H–C–C–C–C–C–C–C–C–C–C–H H H H H H H H H H H

11.1.1 Classification of Organic Compounds

All known organic compounds have been broadly divided into two categories depending upon their carbon skeleton. These are:

(i) Open chain or acyclic compounds.

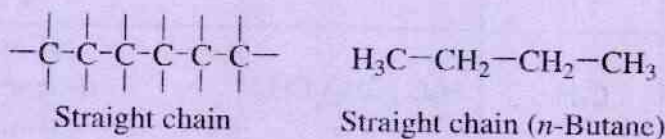
(ii) Closed chain or cyclic compounds.

(i) Open chain or Acyclic compounds

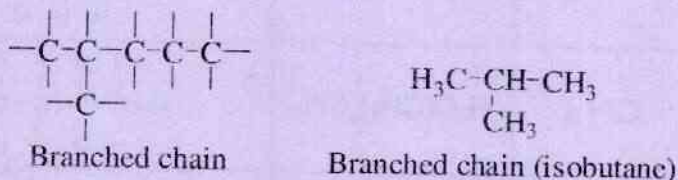
Open chain compounds are those in which the end carbon atoms are not joined with each other in this way they form a long chain of carbon atoms. These chains may be either straight or branched. For example,

(a) *Straight chain compounds* are those in which carbon atoms link with each other through a single, double or triple bonds forming a straight chain such as;

$$-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}}- \qquad H_3C-CH_2-CH_2-CH_3$$

Straight chain — Straight chain (*n*-Butane)

(b) *Branched chain compounds* are those in which there is a branch along a straight chain, such as:

$$-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{-\overset{|}{\underset{|}{C}}-}{C}}-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}}- \qquad H_3C-\underset{CH_3}{\underset{|}{CH}}-CH_3$$

Branched chain — Branched chain (isobutane)

Open chain compounds are also called aliphatic compounds.

(ii) Closed chain or Cyclic compounds

Closed chain or cyclic compounds are those in which the carbon atoms at the end of the chain are not free. They are linked to form a ring. They are further divided into two classes:

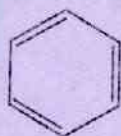
(a) Homocyclic or carbocyclic compounds.

(b) Heterocyclic compounds.

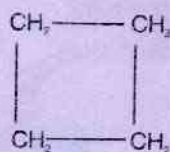
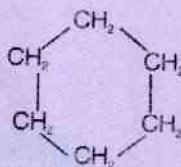
(a) Homocyclic or Carbocyclic compounds.

Homocyclic or carbocyclic compounds contain rings which are made up of only one kind of atoms, i.e., carbon atoms. These are further divided into two classes:

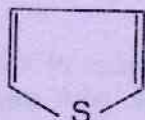
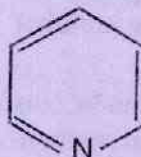
- Aromatic compounds
- Alicyclic compounds

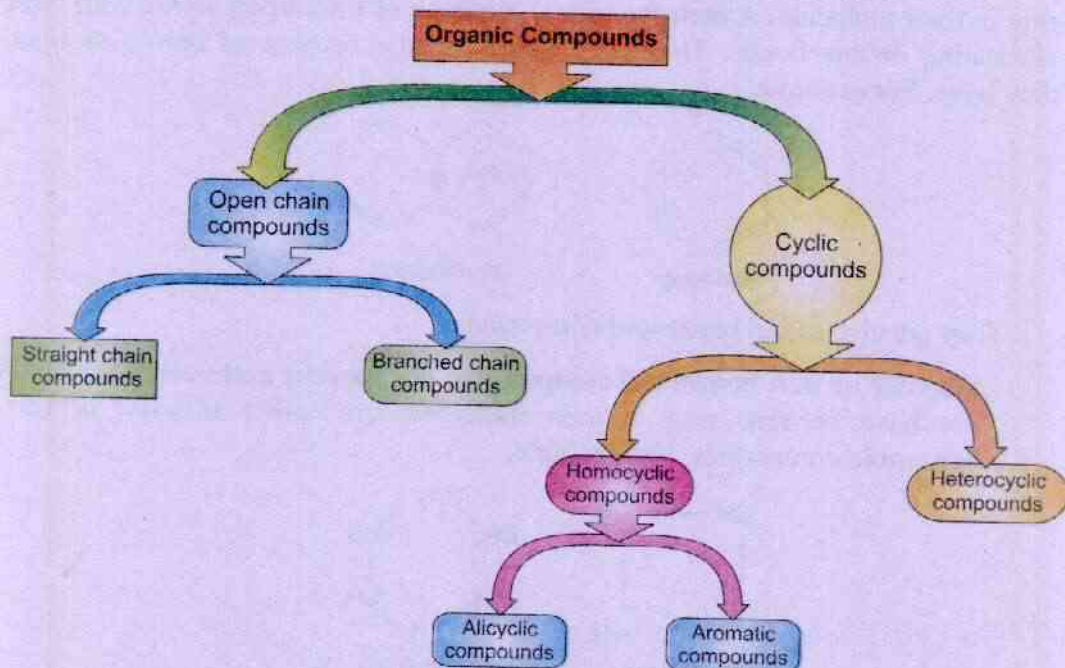
Aromatic compounds: These organic compounds contain at least one benzene ring in their molecule. A benzene ring is made up of six carbon atoms with three alternating double bonds. They are called aromatic because of aroma or smell they have. For example,

Benzene Naphthalene

They are also called benzenoid compounds.

Alicyclic or non-benzenoid compounds: Carbocyclic compounds which do not have benzene ring in their molecules are called alicyclic or non-benzenoid compounds. For example,

Cyclobutane Cyclohexane

(b) Heterocyclic compounds

Cyclic compounds that contain one or more atoms other than that of carbon atoms in their rings are called heterocyclic compounds

Thiophene Pyridine

The classification may be summarized as follows:

11.1.2 Diversity and Magnitude of Organic Compounds

There are a total of 118 elements known today. The number of organic compounds (carbon compounds) is more than ten million. This number is far more than the number of compounds of all the remaining elements taken together. The existence of such a large number of organic compounds is due to the following reasons:

(i) **Catenation:** The main reason for the existence of a large number of organic compounds is that carbon atoms can link with one another by means of covalent bonds to form long chains or rings of carbon atoms. The chains can be straight or branched. The ability of carbon atoms to link with other carbon atoms to form long chains and large rings is called **catenation.**

Two basic conditions for an element to exhibit catenation are :

(a) Element should have valency two or greater than two.

(b) Bonds made by an element with its own atoms should be stronger than the bonds made by the element with other atoms especially oxygen.

Both silicon and carbon have similar electronic configurations but carbon shows catenation whereas silicon does not. It is mainly due to the reason that C–C bonds are much stronger (355 kJ mol^{-1}) than Si–Si (200 kJ mol) bonds. On the other hand, Si – O bonds are much stronger (452 kJ mol^{-1}) than C–O bonds (351 kJ mol^{-1}). Hence, silicon occurs in the form of silica and silicates in nature.

(ii) **Isomerism:**

Another reason for the abundance of organic compounds is the phenomenon of **isomerism.**

The compounds are said to be **isomers** *if they have the same molecular formula but different arrangement of atoms in their molecules or different structural formulae.*

Isomerism also adds to the possible number of structures, e.g., molecular formula C_5H_{12} can be represented by three different structures. Thus, C_5H_{12} has three isomers, as shown below:

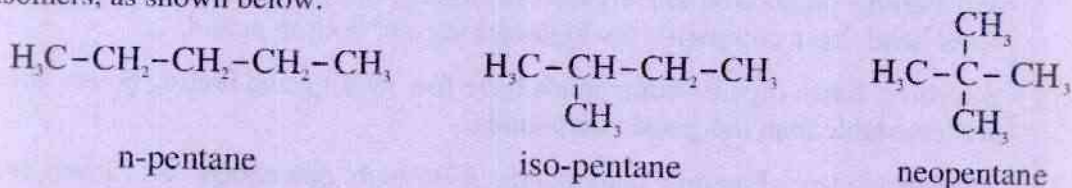
$$H_3C-CH_2-CH_2-CH_2-CH_3$$

n-pentane

$$H_3C-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH_2-CH_3$$

iso-pentane

$$H_3C-\overset{\displaystyle CH_3}{\overset{|}{\underset{\displaystyle CH_3}{\underset{|}{C}}}}-CH_3$$

neopentane

Number of isomers increases with the increase in number of carbon atoms in the given molecular formula.

(iii) **Strength of covalent bonds of carbon:** Due to its very small size, carbon can form very strong covalent bonds with other carbon atoms, hydrogen, oxygen, nitrogen and halogens. This enables it to form a large number of compounds.

(iv) **Multiple bonding:** In order to satisfy its tetravalency, carbon can make multiple bonds (i.e., double and triple bonds). This further adds to the possible number of structures. For example, two carbons in ethane are linked by a single covalent bond, by a double covalent bond in ethylene and a triple covalent bond in acetylene.

11.1.3 General Characteristics of Organic Compounds:

Organic compounds have the following general characteristics:

(i) **Origin:** Naturally occurring organic compounds are obtained from plants and animals. On the other hand inorganic compounds are obtained from minerals and rocks.

(ii) **Composition:** Carbon is an essential constituent of all organic compounds. They are made up of few elements such as carbon, hydrogen, nitrogen, oxygen, halogen, sulphur, etc. On the other hand, inorganic compounds are made up of almost all the elements of the Periodic Table known so far.

(iii) **Covalent linkage:** Organic compounds contain covalent bonds, that may be polar or non-polar, while the inorganic compounds mostly contain ionic bonds.

(iv) **Solubility:** Organic compounds having non-polar linkages are generally soluble in organic solvents like alcohol, ether, benzene, carbon disulphide etc. On the other hand, the inorganic compounds with ionic bonds are soluble in polar solvents like water.

(v) **Electrical conductivity:** Due to the presence of covalent bonds, organic compounds are poor conductor of electricity. Whereas inorganic compounds being ionic in nature, are good conductors of electricity in molten state or in aqueous solution.

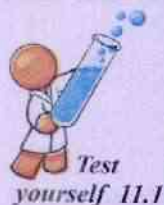
(vi) **Melting and boiling points:** Generally organic compounds have low melting and boiling points and are volatile in nature. Inorganic compounds, on the other hand, have comparatively high melting and boiling points.

(vii) **Stability:** Since organic compounds have low melting and boiling points, they are less stable than inorganic compounds.

(viii) **Combustibility:** Organic compounds with high percentage of carbon are generally combustible. On the other hand, inorganic compounds are mostly non-combustible.

(ix) **Isomerism:** A main characteristics of organic compounds which differentiate them from inorganic substances is their tendency to exhibit the phenomenon of isomerism. Isomerism is rare in inorganic substance.

(x) **Rate of reaction:** Due to the presence of covalent linkages, the reactions of organic compounds are molecular in nature. They are often slow and require specific conditions such as temperature, pressure or catalyst.

Test yourself 11.1

i. Why and how carbon completes its octet?

ii. Point out the properties of carbon which are responsible for formation of long chains of carbon atom compounds.

iii. Why the melting and boiling points of organic compounds are low?

iv. Why the organic compounds are poor conductors of electricity?

v. What are the reasons for the formation of millions of organic compounds?

11.2 SOURCES OF ORGANIC COMPOUNDS

Organic compounds are prepared naturally by animals and plants. Animals synthesize two main groups of organic compounds: proteins and fats. Proteins are meat, mutton, chicken and eggs, etc. Fats are present in milk, butter, etc. Plants synthesize; carbohydrates, proteins, fats, vitamins, etc.

Moreover, dead plants buried under Earth's crust are converted through biochemical processes to coal, petroleum and gas. *These materials are the main sources of organic compounds.* We can get thousands of organic compounds by *the destructive distillation of coal and fractional distillation of petroleum.* Detail for each source is given in figure below:

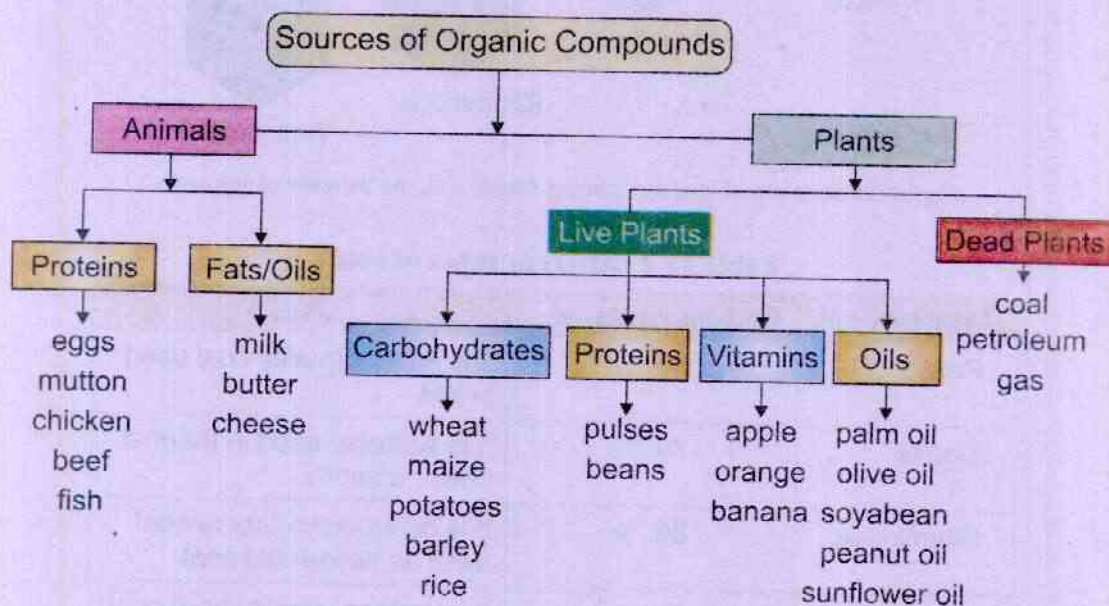



Fig. 11.1 Sources of organic compounds

11.2.1 Coal

***Coal** is blackish, complex mixture of compounds of carbon, hydrogen and oxygen.* It also consists of small amounts of nitrogen and sulphur compounds:

Coal was formed by the decomposition of dead plants buried under the Earth's crust millions of years ago. *Conversion of wood into coal is called* ***carbonization.*** It is a very slow bio-chemical process. It takes place in the absence of air under high pressure and high temperature over a long period of time (about 500 millions of years) as shown in figure 11.2. Wood contains about 40% carbon, so depending upon the extent of carbonization process, four types of coal are found. These types differ with respect to carbon content, volatile matter and moisture. Table 11.2 shows the detail of contents of different types of coals and their uses in daily life and industry.

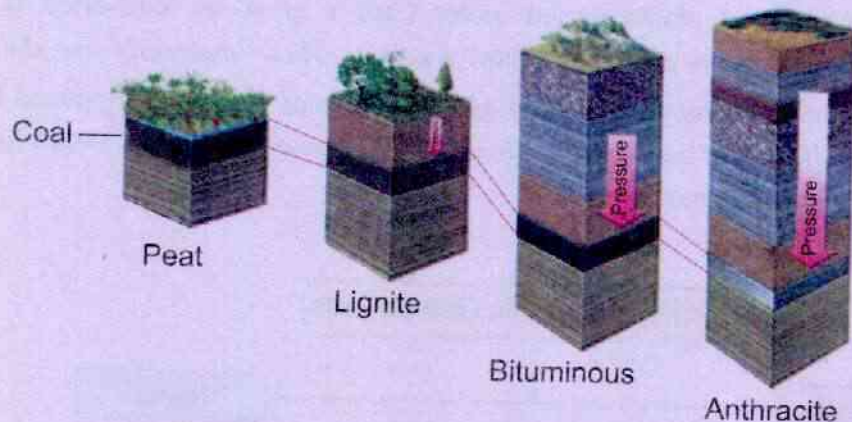



Fig.11.2 Formation of coal in different stages with the increase of pressure.

Table 11.2 Different types of coal

Type of Coal	Carbon contents	Uses
Peat	60 %	It is inferior quality coal used in kiln.
Lignite	70 %	It is soft coal used in thermal power stations.
Bituminous	80 %	It is common variety of coal used as household coal.
Anthracite	90 %	It is superior quality hard coal that is used in industry.

Coal has become a major source of organic compounds because of destructive distillation. *The strong heating of coal in the absence of air is called* ***destructive distillation*****.** As we know coal contains elements like carbon, hydrogen, oxygen, nitrogen and sulphur. So destructive distillation of coal provides a large number of organic compounds along with a few inorganic compounds. These products are:

(i) **Coal Gas** is mixture of hydrogen, methane and carbon monoxide. It produces heat when burnt in air. Therefore, it is mainly used as a fuel in industry. It is also used to provide an inert or reducing atmosphere in various metallurgical processes.

(ii) **Ammonical Liquor** is a solution of ammonia gas in water. It is used to prepare nitrogenous fertilizers. For example, when it is treated with sulphuric acid, it produces ammonium sulphate, fertilizer.

(iii) **Coal Tar** is a thick black liquid. It is a mixture of more than 200 different organic compounds, mostly aromatic. These compounds are separated by fractional distillation. Some of the important aromatic compounds are

benzene, phenol, toluene, aniline, etc. These chemicals are used to synthesize drugs, dyes, explosives, paints, varnishes, plastics, synthetic fibre and pesticides. Besides these valuable chemicals, the *black residue of the coal tar is called pitch.* It is used for surfacing of roads and roofs.

(iv) **Coke** is 98% carbon. It is left behind residue of coal. When coal is subjected to destructive distillation, it loses all its volatile components and *leaves behind a solid residue called coke*. It is mainly used as a reducing agent in the extraction of metals especially iron. It is also used as fuel.

Test yourself 11.2

i. *Name the gases which are found in coal gas.*
ii. *Is coaltar a compound. What is importance of coaltar?*
iii. *What is coke? For what purpose it is used?*
iv. *Which is the best quality of coal?*
v. *What is destructive distillation?*

Interesting Information

Scientists are working on ways to convert coal into gas underground so that it will not have to be mined. This will allow us to use small seams of coal or seams that are dangerous to mine because of weaknesses in the surrounding rocks.

11.2.2 Petroleum

Petroleum *is a dark brownish or greenish black coloured viscous liquid*. It is a complex mixture of several solid, liquid or gaseous hydrocarbons in water mixed with salts and earth particles.

Petroleum is a main source of organic compounds. It consists of several compounds mainly hydrocarbons. These compounds are separated by fractional distillation (separation of fractions or components depending upon their boiling point ranges). These fractions and their uses are provided in table 16.1 in chapter 16. Each fraction is not a single compound, rather each of it consists of different organic compounds.

11.2.3 Natural Gas

It is a mixture of low molecular mass hydrocarbons. The main component about 85% is methane, along with other gases: ethane, propane and butane. Its origin

is similar to that of coal and petroleum. Therefore, it is found with their deposits as shown in figure 11.3. Natural gas is used as fuel in homes as well as in industries. It is used as fuel in automobiles as compressed natural gas (CNG). Natural gas is also used to make carbon black and fertilizer.

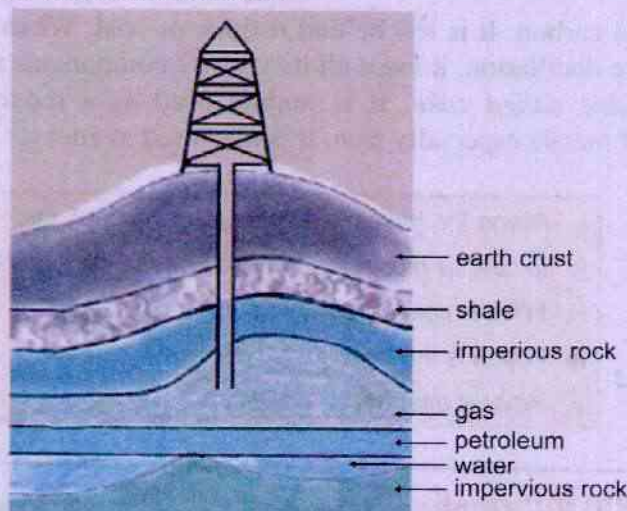



Fig. 11.3 Occurrence and drilling of gas.

11.2.4 Plants

Living plants synthesize macro-molecules, e.g., carbohydrates, proteins oils and vitamins.

The basic unit of all types of carbohydrates is glucose which is synthesized by plants through photosynthesis. Glucose then further polymerizes to form sucrose, starch and cellulose.

Proteins are found in the pulses and beans. Proteins are prepared by the fixation of nitrogen by bacteria found on the roots of plants.

Oils are found in the seeds of plants such as sunflower, rapeseed, palm, coconut and ground-nut.

Vitamins are found in apple and citrus fruits. Besides these major food items, plants also give us gums, rubber, medicines, etc.

11.2.5 Synthesis in Laboratory

Just about two hundred years ago, it was considered that organic compounds could be synthesized only by plants and animals because they possess 'Vital Force', which is very essential for synthesis of organic compounds. But the synthesis of urea (NH_2CONH_2) in laboratory by F.M. Wholer in 1828, opened the discipline on field synthesis of organic compounds in laboratory. Uptil now more than ten million organic compounds have been prepared in the laboratories. They range from simple

to complex compounds. They are present in drugs and medicines; flavours and fragrances; plastics and paints; synthetic fibres and rubber, cosmetics and toiletries and detergents insecticides and pesticides, etc.

11.3 USES OF ORGANIC COMPOUNDS

No doubt, thousands of organic compounds are synthesized naturally by animals and plants. But millions of organic compounds are being prepared in the laboratories by the chemists. Because these compounds are part of everything from food we eat to the various items we use in daily life to fulfill our needs.

(i) **Uses as Food:** The food we eat daily such as milk, eggs, meat, vegetables, etc., contain carbohydrates, proteins, fats, vitamins, etc., are all organic stuff.

(ii) **Uses as Clothing:** All types of clothing (we wear, we use as bed sheets etc.) are made up of natural fibres (cotton, silk and wool, etc.) and synthetic fibres (nylon , dacron and acrylic, etc.) all these are organic compounds.

(iii) **Uses as Houses:** Wood is cellulose (naturally synthesized organic compound). It is used for making houses and furniture of all kinds.

(iv) **Uses as Fuel:** The fuels we use for automobiles and domestic purposes are coal, petroleum and natural gas. These are called fossil fuels. All of these are organic compounds.

(v) **Uses as Medicines:** A large number of organic compounds (naturally synthesized by plants) are used as medicines by us. Most of the life saving medicines and drugs such as antibiotics (inhibit or kill microorganisms which cause infectious diseases) are synthesized in laboratories.

(vi) **Uses as Raw Material:** Organic compounds are used to prepare a variety of materials, such as rubber, paper, ink, drugs, dyes, paints, varnishes, pesticides, etc.

Test yourself 11.3

i. Define petroleum.

ii. What types of compounds are synthesized by plants?

iii. What is the basic unit of carbohydrates and how it is synthesized?

*iv. **CNG** stands for ......*

v. Our existence owe to organic compounds, comment.

11.4 ALKANES AND ALKYL RADICALS

Alkanes are saturated hydrocarbons or paraffins (para means little, affin means affinity). Their general formula is C_nH_{2n+2}, where 'n' is number of carbon atoms. In case of alkanes `n` ranges from 1 to 40. In this way, alkanes form the most important homologous series of compounds.

Homologous Series

Organic compounds are divided into groups of compounds having similar chemical properties. Each group is known as a homologous series. Organic compounds of the same homologous series have the following properties in common:

(i) All members of a series can be represented by a general formula for example general formulae of alkane, alkanes and alkynes are C_nH_{2n+2}, C_nH_{2n} and C_nH_{2n-2}, respectively.

(ii) Successive members of the series differ by one unit of $-CH_2-$ and 14 units in their relative molecular mass.

(iii) They have similar chemical properties (because they contain the same functional group).

(iv) There is a regular change in their physical properties; the melting and boiling points increase gradually with the increase of molecular masses.

(v) They can be prepared by similar general methods.

Hydrocarbons are regarded as parent organic compounds. All other compounds are considered to be derived from them by substituting one or more hydrogen atoms of a hydrocarbon by one or more reactive atom or group of atoms.

Formation of Alkyl Radicals

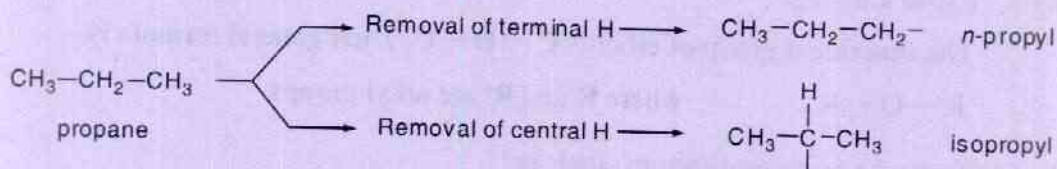
Alkyl radicals *are derivatives of alkanes*. They are formed by the removal of one of the hydrogen atom of an alkane and are represented by a letter 'R'. Their name is written by replacing `ane` of alkane with `yl`. Table 11.3 represents first ten alkanes and their alkyl radicals. Their general formula is C_nH_{2n+1}

Table 11.3 Names and Molecular Formulae of Alkanes and their Alkyl Radicals

Alkane	Molecular Formula	Alkyl radical	Name
Methane	CH_4	CH_3-	Methyl
Ethane	C_2H_6	C_2H_5-	Ethyl
Propane	C_3H_8	C_3H_7-	Propyl
Butane	C_4H_{10}	C_4H_9-	Butyl
Pentane	C_5H_{12}	$C_5H_{11}-$	Pentyl
Hexane	C_6H_{14}	$C_6H_{13}-$	Hexyl
Heptane	C_7H_{16}	$C_7H_{15}-$	Heptyl
Octane	C_8H_{18}	$C_8H_{17}-$	Octyl
Nonane	C_9H_{20}	$C_9H_{19}-$	Nonyl
Decane	$C_{10}H_{22}$	$C_{10}H_{21}-$	Decyl

It is better to explain the type of radicals of propane and butane. Propane has a straight chain structure. When terminal H is removed it is called ***n*-propyl**. When hydrogen from central carbon is removed it is called **isopropyl**, as explained below:

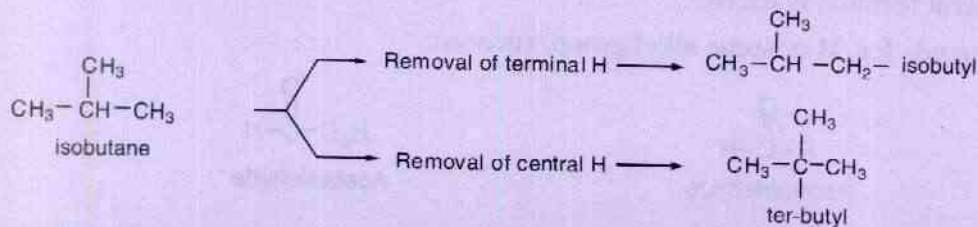
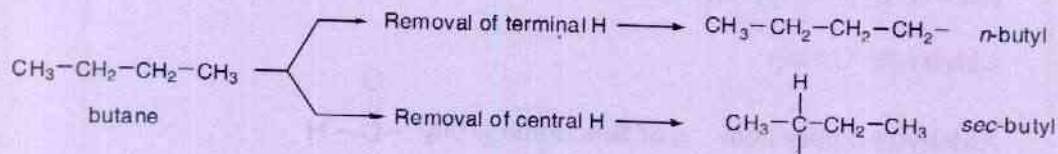
$CH_3-CH_2-CH_3$ (propane)

- Removal of terminal H ⟶ $CH_3-CH_2-CH_2-$ *n*-propyl
- Removal of central H ⟶ $CH_3-\overset{H}{\overset{|}{C}}-CH_3$ (with a free bond on the central C) isopropyl

Similarly, different structures of butyl radicals are explained:

$CH_3-CH_2-CH_2-CH_3$ (butane)

- Removal of terminal H ⟶ $CH_3-CH_2-CH_2-CH_2-$ *n*-butyl
- Removal of central H ⟶ $CH_3-\overset{H}{\overset{|}{C}}-CH_2-CH_3$ (with a free bond on the central C) *sec*-butyl

$CH_3-\overset{CH_3}{\overset{|}{CH}}-CH_3$ (isobutane)

- Removal of terminal H ⟶ $CH_3-\overset{CH_3}{\overset{|}{CH}}-CH_2-$ isobutyl
- Removal of central H ⟶ $CH_3-\overset{CH_3}{\overset{|}{C}}-CH_3$ (with a free bond on the central C) ter-butyl

11.5 FUNCTIONAL GROUPS

An atom or group of atoms or presence of double or triple bond which determines the characteristic properties of an organic compound is known as the functional group. The remaining part of the molecule mainly determines the physical properties such as melting point, boiling point, density, etc. For example, *–OH group is the functional group of alcohols,* which gives characteristics properties of alcohols. The characteristic properties of carboxylic acids are due to the presence of –COOH group in them. Therefore, *functional group of carboxylic acids is –COOH group.*

11.5.1 Functional Groups Containing Carbon, Hydrogen and Oxygen

The organic compounds containing carbon, hydrogen and oxygen as functional group are alcohols, ethers, aldehydes, ketones, carboxylic acids and esters. Their class name, functional group, class formula and examples are given in the Table 11.4.

(i) Alcoholic Group

The functional group of alcohols is –OH. Their general formula is ROH. where R is any alkyl group.

CH_3-OH Methyl alcohol CH_3-CH_2-OH Ethyl alcohol $CH_3-CH_2-CH_2-OH$ n-Propyl alcohol

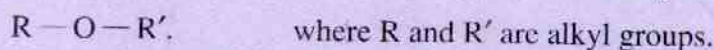
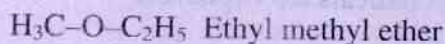
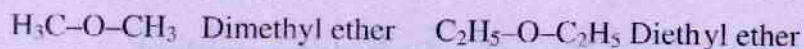
(ii) Ether Linkage

The functional group of ether is $C-O-C$. Their general formula is

$R-O-R'$. where R and R′ are alkyl groups.

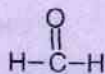
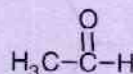
R and R′ may be same or different, such as:

$H_3C-O-CH_3$ Dimethyl ether $C_2H_5-O-C_2H_5$ Diethyl ether

$H_3C-O-C_2H_5$ Ethyl methyl ether

(iii) Aldehydic Group

Aldehyde family con s of functional group $-\overset{O}{\overset{\|}{C}}-H$

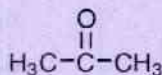
Their general formula is RCHO.

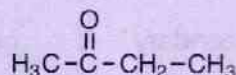
where R stands for H or some alkyl group, such as:

$H-\overset{O}{\overset{\|}{C}}-H$ Formaldehyde $H_3C-\overset{O}{\overset{\|}{C}}-H$ Acetaldehyde

(iv) Ketonic Group

Compounds containing the functional group $>C=O$ are called ketones. They have the general formula $R-\overset{\overset{O}{||}}{C}-R'$

where R and R′ are alkyl groups. They may be same or different, such as:

$$H_3C-\overset{\overset{O}{||}}{C}-CH_3$$

Acetone (Dimethyl ketone)

$$H_3C-\overset{\overset{O}{||}}{C}-CH_2-CH_3$$

Ethyl methyl ketone

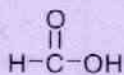
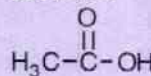
(v) Carboxyl Group

Compounds containing functional group $-\overset{\overset{O}{||}}{C}-OH$ are called carboxylic acids. Their general formula is $R-\overset{\overset{O}{||}}{C}-OH$;

where R stands for — H or some alkyl group. Such as:

$$H-\overset{\overset{O}{||}}{C}-OH$$

Formic acid

$$H_3C-\overset{\overset{O}{||}}{C}-OH$$

Acetic acid

- Perfumes often contain rose oil, which consist of distinct smell giving organic compound geraniol. Geraniol consist of two functional groups; carbon-carbon double bond and the hydroxyl group.

- A sniffing dog can recognize the characteristic smell of human sweat. Each person's sweat contains a unique blend of carboxylic acids.

(vi) Ester Linkage

Organic compounds consisting of RCOOR' functional group are called esters.

Their general formula is $R-\overset{\overset{O}{||}}{C}-OR'$;

where R and R′ are alkyl groups. They may be same or different, such as:

$$H_3C-\overset{\overset{O}{||}}{C}-OCH_3$$

Methyl acetate

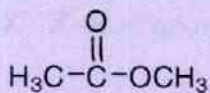
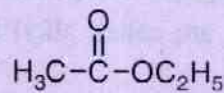
$$H_3C-\overset{\overset{O}{||}}{C}-OC_2H_5$$

Ethyl acetate

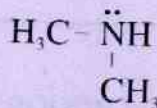
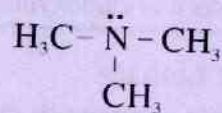
Table 11.4 Functional groups containing carbon, hydrogen and oxygen

Class Name	Functional Group	Class Formula	Examples
Alcohols			
Primary	$-CH_2-OH$	$R-CH_2-OH$	H_3C-CH_2-OH
Secondary	$>CH-OH$	R_2CH-OH	$(H_3C)_2CH-OH$
Tertiary	$-\overset{\vert}{\underset{\vert}{C}}-OH$	R_3C-OH	$(CH_3)_2\overset{CH_3}{C}-OH$
Ethers	$-O-$	$R-O-R$	$H_3C-O-CH_3$
Aldehydes	$-\overset{O}{\overset{\Vert}{C}}-H$	$R-\overset{O}{\overset{\Vert}{C}}-H$	$H_3C-\overset{O}{\overset{\Vert}{C}}-H$
Ketones	$-\overset{O}{\overset{\Vert}{C}}-$	$R-\overset{O}{\overset{\Vert}{C}}-R$	$H_3C-\overset{O}{\overset{\Vert}{C}}-CH_3$
Carboxylic acids	$-\overset{O}{\overset{\Vert}{C}}-OH$	$R-\overset{O}{\overset{\Vert}{C}}-OH$	$H_3C-\overset{O}{\overset{\Vert}{C}}-OH$
Esters	$-\overset{O}{\overset{\Vert}{C}}-OR$	$R-\overset{O}{\overset{\Vert}{C}}-OR$	$H_3C-\overset{O}{\overset{\Vert}{C}}-OC_2H_5$

11.5.2 Functional Group Containing Carbon, Hydrogen and Nitrogen:

The organic compounds containing carbon, hydrogen and nitrogen as functional group are called as amines. Their functional group is $-NH_2$, and their general formula is $R-NH_2$. Examples of amines are:

$H_3C-\ddot{N}H_2$ — Methylamine

$H_3C-\ddot{N}H-CH_3$ — Dimethylamine

$H_3C-\ddot{N}(CH_3)-CH_3$ — Trimethylamine

11.5.3 Functional Group Containing Carbon, Hydrogen and Halogens:

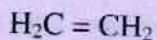
The organic compounds having functional group containing carbon, hydrogen and halogens are called alkyl halides. Their functional group is R–X. 'X' may be F, Cl, Br or I.

Table 11.5 Functional group containing carbon, hydrogen and halogens

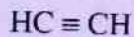
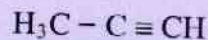
Class Name	Functional Group	Class Formula	Examples
Alkyl Halides			
a. Primary	$-CH_2-X$	$R-CH_2-X$	H_3C-CH_2-X Ethyl halide
b. Secondary	$>CH-X$	R_2CH-X	$(H_3C)_2CH-X$ *sec*-Propyl halide
c. Tertiary	$-\overset{\vert}{\underset{\vert}{C}}-X$	R_3C-X	$(CH_3)_3C-X$ *ter*-Butyl halide

11.5.4 Double and Triple Bond:

Hydrocarbon compounds consisting of double bonds between two carbon atoms in their molecules are called as alkenes, such as:

$$H_2C=CH_2 \qquad H_3C-HC=CH_2$$

Ethene Propene

Hydrocarbon compounds consisting of triple bonds between two carbon atoms in their molecules are called as alkynes, such as:

$$HC\equiv CH \qquad H_3C-C\equiv CH$$

Ethyne (Acetylene) Propyne

11.6 TESTS OF FUNCTIONAL GROUPS

11.6.1 Test for Unsaturation $>C=C<$ or $-C\equiv C-$

(i) **Bromine water test:**

Dissolve a pinch of the given organic compound in 2.0 cm^3 of carbon tetrachloride (CCl_4). Add 2 cm^3 of bromine water in it and shake.

Result: Bromine will be decolourised.

(ii) **Baeyer's test:**

Dissolve about 0.2 g of the organic compound in water. Add to it 2-3 drops of alkaline $KMnO_4$ solution and shake.

Result: Pink colour will disappear.

11.6.2 Test for Alcoholic Group —OH

(i) **Sodium metal test:**

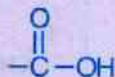
Take about 2-3 cm^3 of the given organic liquid in a dry test tube and add a piece of sodium metal.

Result: Hydrogen gas will evolve.

(ii) **Ester formation test:**

Heat about 1.0 cm^3 of the organic compound with 1.0 cm^3 of acetic acid and 1-2 drops of concentrated sulphuric acid.

Result: Fruity smell will be given out

11.6.3 Test for Carboxyl Group $-\overset{O}{\overset{\|}{C}}-OH$

(i) **Litmus test:**

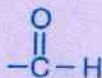
Shake a pinch of the given compound with water and add a drop of blue litmus solution.

Result: Litmus solution will turn red.

(ii) **$NaHCO_3$ solution test:**

Take about 2.0 cm^3 of 5% $NaHCO_3$ solution and add a pinch of given compound.

Result: CO_2 gas with effervescence evolves.

11.6.4 Detection of Aldehydic Group $-\overset{O}{\overset{\|}{C}}-H$

(i) **Sodium bisulphite test:**

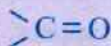
Shake about 0.2 g or 0.5 cm^3 of the given compound with 1-2 cm^3 of saturated solution of sodium bisulphite.

Result: A crystalline white precipitate will be formed.

(ii) **Fehling's solution test:**

Mix equal volumes of Fehling's solution A and B in a test tube. Add a pinch of organic compound and boil for five minutes.

Result: Red precipitate will be formed.

11.6.5 Test for Ketonic Group $>C=O$

(i) **Phenyl hydrazine test:**

Shake a pinch of the given organic compound with about 2.0 cm^3 of phenyl hydrazine solution.

Result: Orange red precipitate will be formed.

(ii) **Sodium nitroprusside test:**

Take about 2.0 cm^3 of sodium nitroprusside solution in a test tube and add 2-3 drops of NaOH solution. Now add a pinch of the given compound and shake.

Result: Red colour will be formed.

(iii) **With Fehling's solution:**

No reaction

11.6.6 Test for Primary Amino Group ($-NH_2$)

(i) **Carbyl amine test:**

Heat about 0.2 g of the given compound and add 0.5 cm^3 of chloroform and add 2-3 cm^3 of alcoholic KOH.

Result: Extremely unpleasant odour will be given out.

11.6.7 Test for Ester

They are recognized by their fruity smell.

Test yourself 11.4

i. *What is the functional group of an ester?*

ii. *What is the difference between aldehydes and ketones?*

iii. *Give the functional groups of alkenes and alkynes.*

iv. *How is an alcohol tested?*

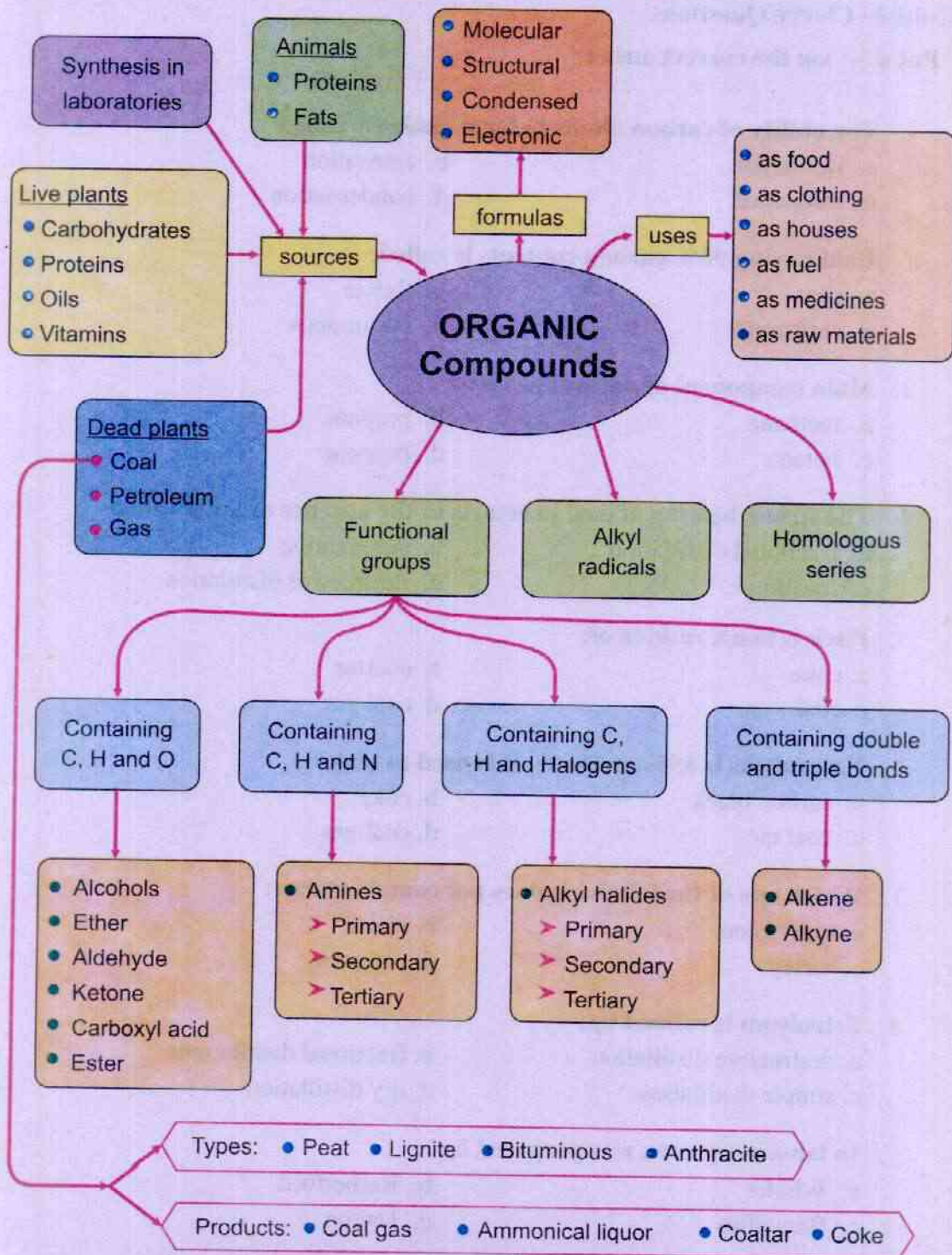
v. *How a ketonic group is tested?*

Pharmaceutical chemists work towards the partial and total synthesis of effective drugs

Synthesise of effective drugs to control the epidemics and fatal diseases is the need of the society. The responsibility to synthesize effective drugs is of pharmaceutical chemists. They can evaluate the efficiency and safety of these drugs. They make the drugs more and more effective by reducing their side effects and enhancing potency.

Key Points

- Organic compounds are compounds of carbon and hydrogen and their derivatives.
- Compounds made up of carbon and hydrogen are called hydrocarbons. They are alkanes, alkenes and alkynes.
- Organic compounds are molecular compounds having covalent bonding.
- They form homologous series of compounds, thus their properties resemble within a series.
- Sources of organic compounds are animals, plants, coal, petroleum and natural gas.
- Dead plants buried under Earth's crust are converted into coal; petroleum and gas. Coal is blackish solid material.
- Coal consists of four types, such as peat, lignite, bituminous and anthracite.
- Destructive distillation of coal produces; coal gas, ammonical liquor; coaltar and coke.
- Petroleum is a dark brownish or greenish black coloured viscous liquid consisting of several compounds. These compounds are separated by fractional distillation.
- Natural gas is a mixture of low molecular mass hydrocarbons. It is mainly used as fuel.
- Living plants synthesize macro-molecules (carbohydrates, proteins, fats and vitamins).
- Organic compounds can also be synthesized in laboratories ranging from the simplest compounds to complex ones.
- Organic compounds have wide range of uses. They are used as food, clothing, housing fuel, medicines and to prepare a variety of materials.
- Alkanes are saturated hydrocarbons, alkyl radicals are derivatives of alkanes which are represented by 'R'.
- An atom or a group of atoms that provide characteristics properties to an organic compound is called functional group.
- Depending upon the functional groups, organic compounds are classified as alcohols, ethers, aldehydes, ketones, carboxylic acids, esters, amines and alkyl halides.

CONCEPT DIAGRAM

EXERCISE

Multiple Choice Questions

Put a (✓)on the correct answer

1. **The ability of carbon atoms to form chains is called**
   a. isomerism
   b. catenation
   c. resonance
   d. condensation

2. **Coal having 90% carbon contents is called:**
   a. peat
   b. lignite
   c. anthracite
   d. bituminous

3. **Main component of natural gas is:**
   a. methane
   b. propane
   c. butane
   d. propene

4. **The strong heating of coal in retorts in the absence of air is called**
   a. fractional distillation
   b. sublimation
   c. roasting
   d. destructive distillation

5. **Pitch is black residue of:**
   a. coke
   b. coal tar
   c. coal
   d. coal gas

6. **Natural gas is 85% methane. It is used to make**
   a. carbon black
   b. coke
   c. coal tar
   d. coal gas

7. **Which one of the following does not contain starch:**
   a. sugar cane
   b. maize
   c. barley
   d. potatoes

8. **Petroleum is refined by:**
   a. destructive distillation
   b. fractional distillation
   c. simple distillation
   d. dry distillation

9. **In laboratory urea was prepared by:**
   a. Wholer
   b. Rutherford
   c. Berzellius
   d. Dalton

10. General formula of alkyl radical is :

a. C_nH_{2n+2} b. $C_n H_{2n-2}$

c. C_nH_{2n+1} d. $C_n H_{2n}$

11. Identify which one of the following compounds is a ketone.

a. $(CH_3)_2CHOH$ b. $(CH_3)_2CO$

c. $(CH_3)_2NH$ d. $(CH_3)_2CHCl$

12. The functional group –COOH is found in:

a. carboxylic acid b. aldehydes

c. alcohols d. esters

13. Which one of the following statements is not true about fossil fuels?

a. they all contain carbon b. they are renewable

c. they produce pollutants when burnt d. they cause acid rain

14. Which one of the following is the hardest coal?

a. peat b. lignite

c. bituminous d. anthracite

15. In which of the following groups, oxygen is attached on both sides with carbon atoms?

a. ketone b. ether

c. aldehyde d. ester

16. Carbonization process is the conversion of:

a. coal into coal gas b. coal into wood

c. wood into coal d. wood into coal tar

17. Coal gas is a mixture of:

a. CO and CH_4 b. CO, CH_4, CO_2

c. CO, CH_4, H_2 d. CO, H_2 and CO_2

18. Which one of the following is a synthetic fibre?

a. cotton b. wool

c. nylon d. silk

19. Which one of the following is not a fossil fuel?

a. coal b. natural gas

c. biogas d. petroleum

20. Which one of the following does not contain protein:

a. pulses b. potatoes

c. beans d. eggs

21. **Conversion of dead plants into coal by the action of bacteria and heat is called:**
    a. carbonization
    b. catenation
    c. hydrogenation
    d. cracking

22. **Which one of the following compounds is an aldehyde?**
    a. CH_3-CH_2-OH
    b. CH_3-COOH
    c. CH_3CHO
    d. CH_3COCH_3

23. **Formula of acetaldehyde is:**
    a. CH_3-CH_2OH
    b. $CH_3-\overset{\overset{O}{||}}{C}-OH$
    c. $CH_3-\overset{\overset{O}{||}}{C}-H$
    d. $H-\overset{\overset{O}{||}}{C}-H$

Short Questions

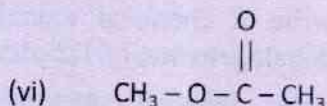
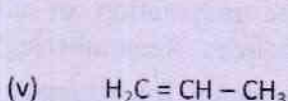
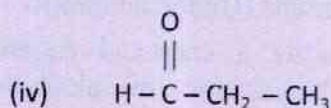
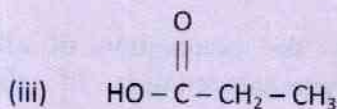
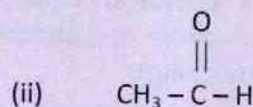
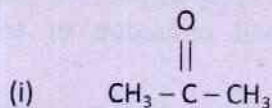
1. What is meant by the term catenation? Give an example of a compound that displays catenation.
2. How is coal formed?
3. What is importance of natural gas?
4. Justify that organic compounds are used as food.
5. How are alkyl radicals formed? Explain with examples.
6. What is the difference between n-propyl and isopropyl? Explain with structure.
7. Explain different radicals of butane.
8. Define functional group with an example.
9. What is an ester group? Write down the formula of ethyl acetate.
10. Write down the dot and cross formulae of propane and n-butane?
11. Define structural formula. Draw the structural formulae of n-butane and isobutane.
12. Write classification of coal.
13. What are heterocyclic compounds? Give two examples.
14. Why benzene and other homologous compounds of benzene are called aromatic compounds?

Extensive Questions

1. (a) How is coal formed? What are the different types of coal?
   (b) Write down the composition and uses of different types of coal.
2. (a) What is destructive distillation of coal?
   (b) Name the different types of the products obtained by the destructive distillation of coal.
3. Write a detailed note on functional groups of alkenes and alkynes. How they are identified from other compounds?
4. Give some uses of organic compounds in our daily life.
5. Write down the characteristics of homologous series.
6. Why organic compounds are numerous?
7. What are amines? Explain the different types of amines giving an example of each type. How primary amino group is identified?
8. Describe the functional group of an alcohol. How alcoholic groups are identified?
9. Differentiate between aldehydic and ketonic functional groups. How both are identified from each other?
10. Encircle the functional groups in the following compounds. Also give the names of the functional groups?

(i) $CH_3-\overset{O}{\overset{||}{C}}-CH_3$ (ii) $CH_3-\overset{O}{\overset{||}{C}}-H$

(iii) $HO-\overset{O}{\overset{||}{C}}-CH_2-CH_3$ (iv) $H-\overset{O}{\overset{||}{C}}-CH_2-CH_3$

(v) $H_2C=CH-CH_3$ (vi) $CH_3-O-\overset{O}{\overset{||}{C}}-CH_3$

11. What are general properties of organic compounds?
12. Write a detailed note on classification of organic compounds.

Students Learning Outcomes

Student will be able to:

- explain why a systematic method of naming chemical compounds is necessary. (Analyzing);
- characterize a hydrocarbon. (Understanding);
- distinguish between saturated and unsaturated hydrocarbons. (Understanding);
- name of alkanes upto decane. (Remembering);
- draw electron cross and dot structures of simple alkanes. (Applying);
- write a chemical equation to show the preparation of alkanes from hydrogenation of alkenes and alkynes and reduction of alkyl halides (Remembering);
- draw structural formulas of alkanes, alkenes and alkynes upto 5 carbon atoms (Understanding);
- write a chemical equation to show the preparation of alkenes from dehydration of alcohols and dehydrohalogenation of alkyl halides (Remembering);
- write a chemical equation to show the preparation of alkynes from dehalogenation of 1,2- dihalides and tetrahalides (Remembering);
- write chemical equations showing halogenation for alkanes, alkenes and alkynes (Remembering) and
- write a chemical equations showing reaction of $KMnO_4$ with alkenes and alkynes (Remembering);

Introduction:

The simplest class of organic compounds is hydrocarbons (compounds consisting of only carbon and hydrogen elements). Carbon is the only element capable of forming stable, extended chains of atoms bonded through single, double, or triple bonds. Hydrocarbons are divided into four general classes, depending upon the nature of bonds present in the molecules. These are alkanes, alkenes, alkynes and aromatics. Each carbon atom of a hydrocarbon has four bonds.

Hydrocarbons are further classified as saturated and unsaturated. The members of these classes have different chemical properties because of different nature of bonds present in them. However, their physical properties are similar because of comparable electronegativities of carbon and hydrogen. Thus, they are almost nonpolar and insoluble in water. They dissolve readily in nonpolar solvents. They are gases or volatile liquids and their volatility decreases with the increase of molecular mass. That is the reason low molecular mass hydrocarbons are gases at room temperature, such as: CH_4 and C_2H_6. Moderate molecular mass hydrocarbons are liquids, such as, C_6H_{14}; while higher molecular mass hydrocarbons are solids.

Fossil fuels are hydrocarbons. They are not only major sources of energy but also are raw materials used to make thousands of consumer products. Hydrocarbons are the starting materials for the synthesis of organic chemicals of commercial importance. These chemicals are essential for making plastics, synthetic rubbers, synthetic fibres, and fertilizers, etc.

Hydrocarbons

Hydrocarbons are those compounds which are made up of only carbon and hydrogen elements.

Hydrocarbons are regarded as the parent organic compounds since other organic compounds are considered to be derived from them by the replacement of one or more hydrogen atoms by other atoms or group of atoms.

Types of Hydrocarbons

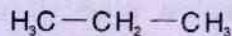
On the basis of structure, hydrocarbons are divided into two main classes:

(i) **Open chain or Aliphatic hydrocarbons:** These are the compounds in which the first and the last carbon are not directly joined to each other. The open chains of carbon may be straight or branched.

For example;

$$H_3C-CH_2-CH_2-CH_3$$

Straight chain (*n*-butane)

```
H3C — CH2 — CH3
       |
      CH3
```

Branched chain (isobutane)

Types of open chain hydrocarbons

Open chain hydrocarbons have been further subdivided into saturated and unsaturated hydrocarbons.

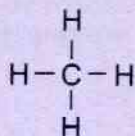
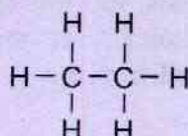
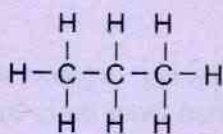
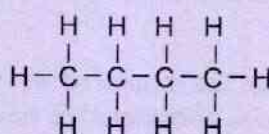
(a) Saturated hydrocarbons

The hydrocarbon in which all the four valencies of carbon atoms are fully satisfied (saturated) by single bonds with other carbon atoms and hydrogen atoms are called saturated hydrocarbons. Saturated hydrocarbons are also called **alkanes.** Thus, an alkane is a hydrocarbon in which the carbon atoms are connected by only single covalent bond (there are no double or triple covalent bonds in alkanes).

Methane (CH_4), ethane (C_2H_6), propane (C_3H_8) and butane (C_4H_{10}) are all saturated hydrocarbons because they contain only carbon-carbon single bonds, as shown below:

```
    H              H   H
    |              |   |
H - C - H      H - C - C - H
    |              |   |
    H              H   H
```

Methane   Ethane

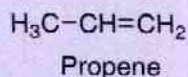
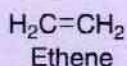
```
    H   H   H              H   H   H   H
    |   |   |              |   |   |   |
H - C - C - C - H      H - C - C - C - C - H
    |   |   |              |   |   |   |
    H   H   H              H   H   H   H
```

Propane   Butane

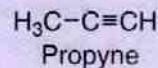
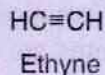
The **general formula** of saturated hydrocarbons is C_nH_{2n+2}, where n is the number of carbon atoms in one molecule of the alkane.

(b) Unsaturated hydrocarbons:

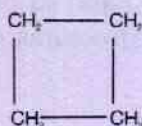
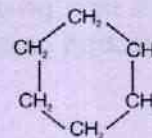
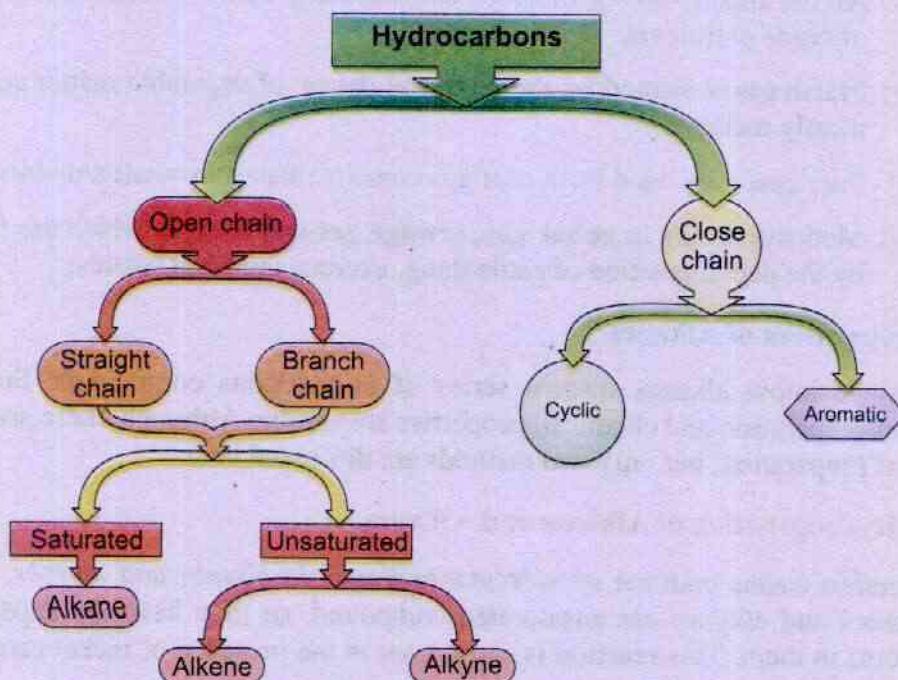
The hydrocarbons in which two carbon atoms are linked by a double or a triple bond are called unsaturated hydrocarbons. The compounds in which two carbon atoms are linked by a double bond are called alkenes. For example, ethene and propene.

$H_2C=CH_2$
Ethene

$H_3C-CH=CH_2$
Propene

These compounds have general formula C_nH_{2n} and functional group $>C=C<$.

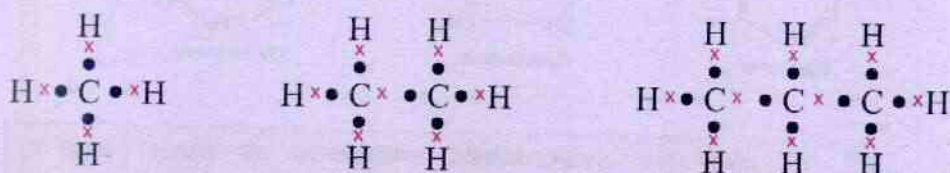
The hydrocarbons in which two carbon atoms are linked by a triple bond are called alkynes. For example, ethyne and propyne.

They have general formula C_nH_{2n-2} and functional group $-C\equiv C-$.

(ii) **Closed chain or Cyclic hydrocarbons:** Compounds having rings of carbon atoms in their molecules are called **closed chain** or **cyclic hydrocarbons,** e.g. benzene (C_6H_6), cyclobutane and cyclohexane.

Benzene   Cyclobutane   Cyclohexane

i. Why are hydrocarbons considered as parent organic compounds?
ii. What is the difference between a straight and a branched chain hydrocarbons?
iii. Give the general formulae of saturated and unsaturated hydrocarbons.
iv. Define unsaturated hydrocarbons with examples.

12.1 ALKANES

The simplest hydrocarbons are alkanes. In these compounds all the bonds of carbon atoms are single that means valencies carbon atoms are saturated. Therefore, they are least reactive. That is the reason, **alkanes are called paraffins** (para means less, and affins means affinity or reactivity).

Alkanes form a homologous series of compounds in which each successive member of the series differs by a CH_2 group but they have similar structures and similar chemical properties. The first member of the series is methane (CH_4), next ethane (C_2H_6), then next propane (C_3H_8) and so on as given in the previous chapter Table 11.3. The electron cross and dot structures of simple alkanes are presented as follows:

$$\begin{array}{ccc} & H & \\ & \overset{\times}{\bullet} & \\ H\times\bullet & C & \bullet\times H \\ & \underset{\times}{\bullet} & \\ & H & \end{array} \qquad \begin{array}{cccc} & H & H & \\ & \overset{\times}{\bullet} & \overset{\times}{\bullet} & \\ H\times\bullet & C\times\ \bullet & C & \bullet\times H \\ & \underset{\times}{\bullet} & \underset{\times}{\bullet} & \\ & H & H & \end{array} \qquad \begin{array}{ccccc} & H & H & H & \\ & \overset{\times}{\bullet} & \overset{\times}{\bullet} & \overset{\times}{\bullet} & \\ H\times\bullet & C\times\ \bullet & C\times\ \bullet & C & \bullet\times H \\ & \underset{\times}{\bullet} & \underset{\times}{\bullet} & \underset{\times}{\bullet} & \\ & H & H & H & \end{array}$$

Sources of Alkanes

(i) The main sources of alkanes are petroleum and natural gas.

(ii) Methane forms about 85% of natural gas.

(iii) All the alkanes are be obtained commercially by the fractional distillation of crude petroleum.

(iv) Marsh gas is formed by the bacterial decay of vegetable matter contains mostly methane.

(v) Fuel gases obtained from coal gas contain alkanes in small amounts.

(vi) Methane occurs in **gobar gas, sewage gas** and **bio-gas** which are formed by the decomposition of cattle dung, excreta and plant wastes.

12.1.1 Preparation of Alkanes

As we know alkanes form a series of homologous compounds. So, their methods of preparation and chemical properties are similar. Although, there are many methods of preparation, but only two methods are discussed here.

12.1.1.1 Hydrogenation of Alkenes and Alkynes

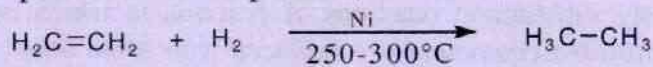
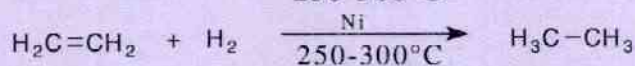
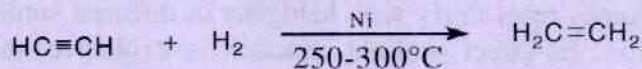
***Hydrogenation** means addition of molecular hydrogen in alkenes and alkynes.* As we know alkenes and alkynes are unsaturated compound, so they have the capacity to add up atoms in them. This reaction is carried out in the presence of nickel catalyst at

250 °C to 300 °C. However, in the presence of catalyst platinum or palladium, the reaction takes place at room temperature, such as:

$$H_2C{=}CH_2 + H_2 \xrightarrow[250\text{-}300°C]{Ni} H_3C{-}CH_3$$

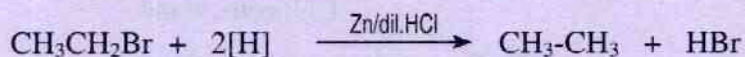
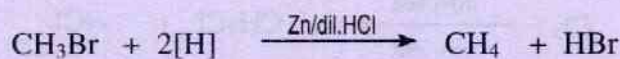
Similarly,

$$HC{\equiv}CH + H_2 \xrightarrow[250\text{-}300°C]{Ni} H_2C{=}CH_2$$

$$H_2C{=}CH_2 + H_2 \xrightarrow[250\text{-}300°C]{Ni} H_3C{-}CH_3$$

12.1.1.2 Reduction of Alkyl Halides

Reduction *means addition of nascent hydrogen.* In fact, it is a replacement of a halogen atom with a hydrogen atom. This reaction takes place in the presence of Zn metal and HCl.

$$CH_3Br + 2[H] \xrightarrow{Zn/dil.HCl} CH_4 + HBr$$

$$CH_3CH_2Br + 2[H] \xrightarrow{Zn/dil.HCl} CH_3\text{-}CH_3 + HBr$$

Physical Properties of Alkanes.

(i) Alkanes form a homologous series of compounds of first four members of the series are gases. The alkanes consisting of C_5 to C_{10} are liquids while higher members of the series are solids.

(ii) They are nonpolar, therefore, they are insoluble in water but soluble in organic solvents.

(iii) The density of alkanes increases gradually with the increase of molecular size.

(iv) The melting and boiling points of alkanes increase regularly with the increase of molecular sizes. This is because of increase of attractive forces between the molecules of alkanes.

(v) The alkanes become more viscous as their molecular sizes increase.

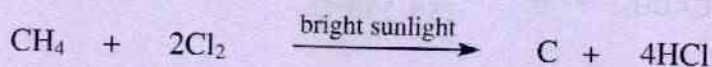
(vi) Alkanes become less flammable, i.e. more difficult to burn with the increase of molecular sizes.

12.1.2 Chemical Reactions

Alkanes are least reactive compounds being saturated hydrocarbons. However, they give reactions at high temperatures. Here we will discuss only two reactions of alkanes.

12.1.2.1 Halogenation

Alkanes give only substitution reactions. *A reaction in which one or more hydrogen atoms of a saturated compound are replaced with some other atoms (like halogen) is called a substitution reaction.* These reactions are a characteristic property of alkanes. Alkanes react fairly with halogens in diffused sunlight only. In dark there is no reaction. In direct sunlight, reaction is explosive and carbon is deposited.

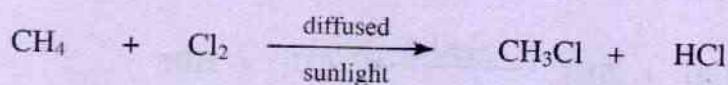
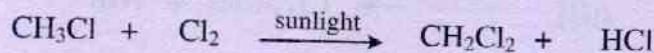
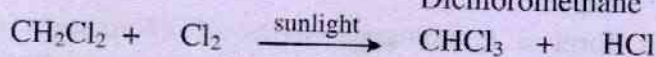
$$CH_4 + 2Cl_2 \xrightarrow{\text{bright sunlight}} C + 4HCl$$

In diffused sunlight, a series of reactions take place and at each step one hydrogen atom is substituted by halogen atoms, so that all the hydrogen atoms are substituted one by one by halogen atoms

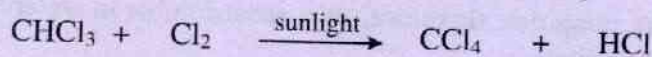
$$CH_4 + Cl_2 \xrightarrow[\text{sunlight}]{\text{diffused}} CH_3Cl + HCl$$

Chloromethane

$$CH_3Cl + Cl_2 \xrightarrow{\text{sunlight}} CH_2Cl_2 + HCl$$

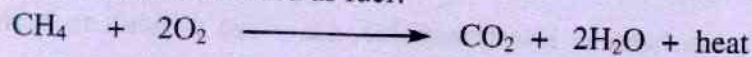
Dichloromethane

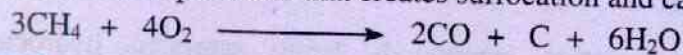
$$CH_2Cl_2 + Cl_2 \xrightarrow{\text{sunlight}} CHCl_3 + HCl$$

Trichloromethane
(Chloroform)

$$CHCl_3 + Cl_2 \xrightarrow{\text{sunlight}} CCl_4 + HCl$$

Tetrachloromethane
(Carbon tetrachloride)

12.1.2.2 Combustion

Alkanes burn in the presence of excess of air or oxygen to produce a lot of heat, carbon dioxide and water. This reaction takes place in automobile combustion engines, domestic heaters and cooking appliances. It is highly exothermic reaction and because of it alkanes are used as fuel.

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O + \text{heat}$$

In the limited supply of oxygen, there is incomplete combustion. As a result, carbon monoxide is produced that creates suffocation and causes death.

$$3CH_4 + 4O_2 \longrightarrow 2CO + C + 6H_2O$$

Uses of Methane and Ethane

(i) Natural gas that is chiefly methane is used as domestic fuel.

(ii) Compressed natural gas (CNG) is used as automobile fuel.

(iii) These gases are used in the manufacture of chemicals such as carbon black, methyl alcohol, ethyl alcohol, chloroform, carbon tetrachloride, formaldehyde and acetaldehyde.

These chemicals are used in daily life, such as carbon black is used in the manufacture of shoe polishes, printers ink and as a filler in rubber industry.

Chloroform is used as a solvent for rubber, waxes, etc., and for anaesthesia.

Carbon tetrachloride is used as an industrial solvent and in dry cleaning.

Test yourself 12.2

i. Which is the simplest alkane?

ii. Give the structural formulas:
isopentane, and isobutane

iii. Why the burning of alkanes require sufficient supply of oxygen?

iv. What do you mean by halogenation? Give the reaction of methane with chlorine in bright sunlight.

Interesting Information

- Poke around with a stick in the muddy bottom of a pond or marsh. You may see bubbles coming up out of the mud. These bubbles are the hydrocarbon gas methane, which is also called 'marsh gas'. If you collect the gas in a jam jar you can set fire to it.
- Orchids produce alkanes to attract bees to pollinate their flowers.

12.2 ALKENES

The simplest alkene is ethene having formula C_2H_4. These compounds are also known as olefins (a Latin word meaning oil forming) because first members form oily products when react with halogens.

A few alkenes with their molecular, condensed, structural and cross and dot formulae are given in Table 12.1.

Table 12.1 Molecular, Condensed, Structural and Electronic Formulae of Alkenes

Name	Molecular formula	Condensed formula	Structural formula	Cross and dot formula
(i) Ethylene or ethene	C_2H_4	$H_2C = CH_2$	$\begin{smallmatrix}H\\H\end{smallmatrix}\!>C=C<\!\begin{smallmatrix}H\\H\end{smallmatrix}$	$\begin{smallmatrix}H\\H\end{smallmatrix}\!\times C :: C \times\!\begin{smallmatrix}H\\H\end{smallmatrix}$
(ii) Propylene or propene	C_3H_6	$H_3C - HC = CH_2$	$H-\underset{H}{\overset{H}{C}}-\overset{H}{C}=C<\!\begin{smallmatrix}H\\H\end{smallmatrix}$	$H\times\underset{H}{\overset{H}{C}}\times\overset{H}{C} :: C\!\begin{smallmatrix}H\\H\end{smallmatrix}$
(iii) Butylene or butene	C_4H_8	$H_3C{-}H_2C{-}HC{=}CH_2$	$H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\overset{H}{C}=C<\!\begin{smallmatrix}H\\H\end{smallmatrix}$	$H\times\underset{H}{\overset{H}{C}}\times\underset{H}{\overset{H}{C}}\times\overset{H}{C} :: C\!\begin{smallmatrix}H\\H\end{smallmatrix}$
(iv) Pentene	C_5H_{10}	$H_3C{-}CH_2{-}CH_2CH{=}CH_2$	$H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\overset{H}{C}=C<\!\begin{smallmatrix}H\\H\end{smallmatrix}$	$H\times\underset{H}{\overset{H}{C}}\times\underset{H}{\overset{H}{C}}\times\underset{H}{\overset{H}{C}}\times\overset{H}{C} :: C\!\begin{smallmatrix}H\\H\end{smallmatrix}$

Occurrence

(i) Alkenes being more reactive than alkanes, seldom occur free in nature.

(ii) Lower alkenes occur in coal gas in minute quantities.

(iii) Ethylene is present in natural gas sometimes to the extent of 20%.

(iv) Alkenes are produced in large amounts by cracking of petroleum.

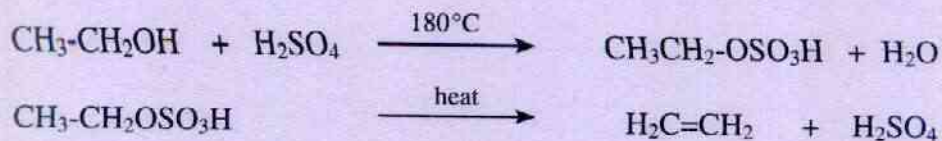
12.2.1 Preparation of Alkenes

Alkenes are prepared by the removal of small atoms (H,OH,X) from the adjacent carbon atoms of the saturated compounds, so as to create a double bond between carbon atoms.

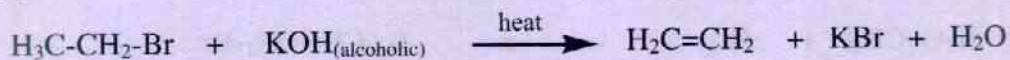
12.2.1.1 Dehydration of Alcohols

Dehydration is removal of water. Ethene is prepared by heating a mixture of ethanol and excess of concentrated sulphuric acid at 180°C. In first step, ethyl hydrogen sulphate is formed which decomposes on heating to produce ethene, which is collected over water.

$$CH_3\text{-}CH_2OH + H_2SO_4 \xrightarrow{180°C} CH_3CH_2\text{-}OSO_3H + H_2O$$

$$CH_3\text{-}CH_2OSO_3H \xrightarrow{heat} H_2C{=}CH_2 + H_2SO_4$$

12.2.1.2 Dehydrohalogenation of Alkyl halides

On heating, ethyl bromide with alcoholic KOH, ethene is formed. Removal of hydrogen and halogen takes place from adjacent carbon atoms to create a double bond.

$$H_3C\text{-}CH_2\text{-}Br \;+\; KOH_{(alcoholic)} \xrightarrow{\text{heat}} H_2C{=}CH_2 \;+\; KBr \;+\; H_2O$$

Physical Properties of Alkenes

(i) The first member of the alkenes is ethene. It is a colourless gas with pleasant odour.

(ii) Alkenes are nonpolar, therefore, they are insoluble in water but soluble in organic solvents.

(iii) The first member of the series ethene is slightly less dense than air.

(iv) Alkenes are flammable hydrocarbons. On complete combustion, they form carbon dioxide and water with release of energy. However, their flame is smokier than alkanes having a similar number of carbon atoms.

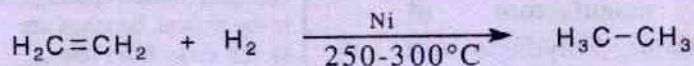
(v) Their melting and boiling points gradually increase with the increase of molecular sizes of the compounds in the series.

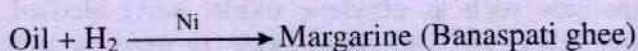
12.2.2 Chemical Reactions

Alkenes are reactive compounds because the electrons of the double bond are easily available for reaction. These compounds have the tendency to react readily by adding other atoms, to become saturated compounds. As a result, the double bond is converted into a single bond that is more stable. Thus, addition reactions are characteristic property of unsaturated compounds. *These are the reactions in which the products are formed by the addition of some reagents like* H_2 , Cl_2 , *etc., to an unsaturated organic compound.* In the process, one of the bonds of a double bond gets broken and two new single bonds are formed.

12.2.2.1 Hydrogenation of Alkenes

Hydrogenation means addition of molecular hydrogen to an unsaturated hydrocarbon in the presence of a catalyst (Ni, Pt) to form saturated compound.

$$H_2C{=}CH_2 \;+\; H_2 \xrightarrow[250\text{-}300^{\circ}C]{Ni} H_3C{-}CH_3$$

On industrial scale, this reaction is used to convert vegetable oil into margarine (Banaspati ghee).

$$\text{Oil} + H_2 \xrightarrow{Ni} \text{Margarine (Banaspati ghee)}$$

12.2.2.2 Halogenation of Alkenes

Halogenation means addition of halogen like chlorine or bromine. Bromination of alkenes is very important reaction . When bromine water (a solution of bromine in water having red-brown colour) is added to ethene in an inert solvent like carbon tetrachloride, its colour is discharged at once.

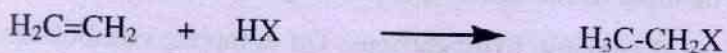
$$H_2C{=}CH_2 + Br_2 \longrightarrow Br\text{-}CH_2\text{-}CH_2\text{-}Br$$

In the reaction, double bond of ethene is converted into a single bond by the addition of a molecule of bromine. *This reaction is used to identify the unsaturation of an organic compound.*

12.2.2.3 Hydrohalogenation of Alkenes

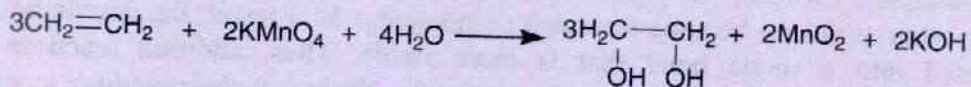
Dry gaseous hydrogen halides (HI, HBr and HCl) react with alkenes to produce alkyl halides.

$$H_2C{=}CH_2 + HX \longrightarrow H_3C\text{-}CH_2X$$

$$H_2C{=}CH_2 + HBr \longrightarrow H_3C\text{-}CH_2Br$$

The order of reactivity of hydrogen halides is $HI > HBr > HCl$.

12.2.2.4 Oxidation of Alkenes with $KMnO_4$

Alkenes decolourize the pink colour of acidified dilute solution of potassium permanganate because the double bond electrons react with MnO_4^- ion, which further goes on to form MnO_2 and of ethene glycol (1,2-ethanediol). Such as, there is addition of two 'hydroxyl group' at the double bond.

$$3CH_2{=}CH_2 + 2KMnO_4 + 4H_2O \longrightarrow 3\underset{OH}{\underset{|}{H_2C}}\text{—}\underset{OH}{\underset{|}{CH_2}} + 2MnO_2 + 2KOH$$

This reaction is also used to test the unsaturation in an organic compound.

Uses of Ethene (Ethylene)

Ethene is used:

(i) for artificial ripening of fruits;

(ii) as a general anaesthetic;

(iii) for manufacture of polythene. Polythene is a plastic material used in packaging, toys, bags, etc;

(iv) as a starting material for the manufacture of a large number of compounds such as ethylene oxide, ethyl alcohol, ethylene glycol, diethyl ether, etc.; ethylene oxide is used as a fumigant, ethylene

glycol is used as an anti-freeze, diethyl ether and ethyl alcohol are used as solvents and

(v) for making poisonous mustard gas which is used in chemical warfare.

Test yourself 12.3

i. *Why are alkenes reactive?*

ii. *How can you prepare propene from propyl alcohol?*

iii. *Give a test used to identify unsaturation of an organic compound.*

iv. *Give a few uses of ethene.*

12.3 ALKYNES

The simplest alkyne is acetylene, with molecular formula C_2H_2. Alkynes are also called acetylenes because of the name of the first member of the series is acetylene.

Molecular, condensed, structural and dot and cross formulae of a few alkynes are given in Table 12.2.

Table 12.2 Molecular, Condensed, Structural and Electronic Formulae of Alkynes

Name	Molecular formula	Condensed formula	Structural formula	Cross and dot formula
(i) Acetylene (ethyne)	C_2H_2	$HC \equiv CH$	$H-C\equiv C-H$	$H\times\cdot C \vdots\vdots C \cdot\times H$
(ii) Methyl Acetylene (propyne)	C_3H_4	$H_3C-C\equiv CH$	$H-\underset{H}{\overset{H}{\overset{\vert}{\underset{\vert}{C}}}}-C\equiv C-H$	$H\times\cdot\underset{H}{\overset{H}{C}}\cdot\times C\vdots\vdots C\cdot\times H$
(iii) Dimethyl Acetylene (butyne)	C_4H_6	$H_3C-C\equiv C-CH_3$	$H-\underset{H}{\overset{H}{\overset{\vert}{\underset{\vert}{C}}}}-C\equiv C-\underset{H}{\overset{H}{\overset{\vert}{\underset{\vert}{C}}}}-H$	$H\times\cdot\underset{H}{\overset{H}{C}}\cdot\times C\vdots\vdots C\cdot\times\underset{H}{\overset{H}{C}}\cdot\times H$

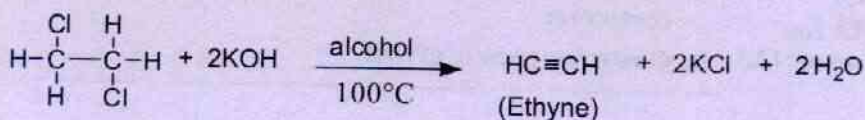
Occurrence: Acetylene does not occur free in nature. Traces of acetylene are present in coal gas (about 0.06%).

12.3.1 Preparation of Alkynes

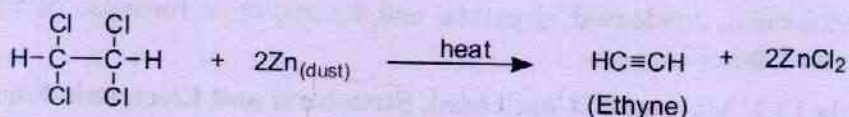
Alkynes are prepared by the following methods.

12.3.1.1 Dehydrohalogenation of Vicinal Dihalides

When a vicinal dihalide is heated with alcoholic KOH, two hydrogen atoms along with two halogen atoms are removed from two adjacent carbon atoms with the formation of a triple bond between the adjacent carbons:

$$\text{H}-\underset{\text{H}}{\overset{\text{Cl}}{\text{C}}}-\underset{\text{Cl}}{\overset{\text{H}}{\text{C}}}-\text{H} + 2KOH \xrightarrow[100°C]{\text{alcohol}} \underset{\text{(Ethyne)}}{HC{\equiv}CH} + 2KCl + 2H_2O$$

12.3.1.2. Dehalogenation of Tetrahalides

When alkyl tetrahalides are heated with Zinc dust, the elimination of halogen atoms takes place to form ethyne.

$$\text{H}-\underset{\text{Cl}}{\overset{\text{Cl}}{\text{C}}}-\underset{\text{Cl}}{\overset{\text{Cl}}{\text{C}}}-\text{H} + 2Zn_{(dust)} \xrightarrow{\text{heat}} \underset{\text{(Ethyne)}}{HC{\equiv}CH} + 2ZnCl_2$$

Physical Properties

(i) Alkynes also form a series of compounds. Its first member is acetylene. It is a colourless gas with faint garlic odour.

(ii) Acetylene is slightly soluble in water but soluble in organic solvents such as benzene, alcohol, acetone, ether, etc.

(iii) Acetylene is slightly lighter than air.

(iv) Alkynes are also flammable. They produce smokier flames than those of alkanes and alkenes.

12.3.2 Chemical Reactions

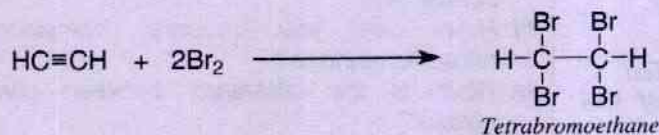
Alkynes are reactive compounds because of presence of a triple bond. A triple bond consists of two weak bonds and a strong bond. When alkynes react with other substances, two weak bonds are readily broken one by one and addition takes place easily. The addition reactions of alkynes resemble to those of alkenes.

12.3.2.1 Addition of Halogen

Chlorine and bromine adds to acetylene to form tetrachloroethane and tetrabromoethane, respectively. When bromine water is added to acetylene, red-

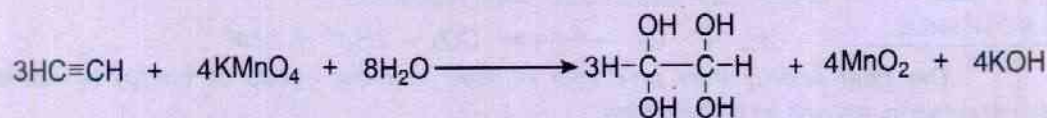
brown colour of bromine water is discharged rapidly due to formation of colourless tetrabromoethane.

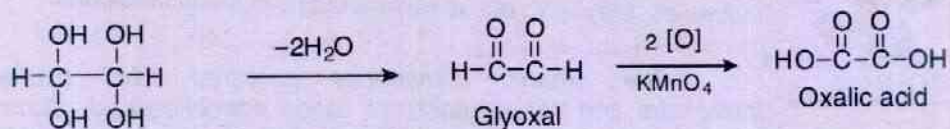
$$HC{\equiv}CH + 2Br_2 \longrightarrow H-\underset{Br}{\overset{Br}{C}}-\underset{Br}{\overset{Br}{C}}-H$$

Tetrabromoethane

This reaction is used to identify the unsaturation of alkynes.

12.3.2.2 Oxidation with $KMnO_4$.

Ethyne is oxidized by alkaline $KMnO_4$. And four hydroxyl groups add to the triple bond, such as:

$$3HC{\equiv}CH + 4KMnO_4 + 8H_2O \longrightarrow 3H-\underset{OH}{\overset{OH}{C}}-\underset{OH}{\overset{OH}{C}}-H + 4MnO_2 + 4KOH$$

This intermediate product eliminates water molecules to form glyoxal, which is further oxidized to form oxalic acid.

$$H-\underset{OH}{\overset{OH}{C}}-\underset{OH}{\overset{OH}{C}}-H \xrightarrow{-2H_2O} \underset{\text{Glyoxal}}{H-\overset{O}{\overset{\|}{C}}-\overset{O}{\overset{\|}{C}}-H} \xrightarrow[KMnO_4]{2\,[O]} \underset{\text{Oxalic acid}}{HO-\overset{O}{\overset{\|}{C}}-\overset{O}{\overset{\|}{C}}-OH}$$

Uses of Acetylene

(i) Acetylene produces oxy-acetylene flame with oxygen. It is a highly exothermic reaction. Heat released is used for welding purposes.

(ii) Acetylene is used to prepare other chemicals, such as alcohols, acetaldehyde and acids.

(iii) It is used for the ripening of fruits.

(iv) It is used for the manufacturing of polymer products like polyvinyl chloride, polyvinyl acetate and synthetic rubber like neoprene.

(v) It is polymerized to form benzene, which is used as raw material to form a variety of organic compounds.

i. Why the alkynes are called acetylenes?
ii. How is tetrabromoethane prepared from acetylene?
iii. How can you prepare acetylene from tetrachloroethane?
iv. What is the difference between glycol and glyoxal?
v. Write the formula of oxalic acid.

Hydrocarbons as Fuel

The main constituents of fuels (coal, petroleum and natural gas) are hydrocarbons. When hydrocarbons are burnt in air the reaction is called combustion. It is highly exothermic reaction, i.e. it produces a lot of heat. The basic combustion reaction is

$$CH_4 + O_2 \xrightarrow{2} CO_2 + 2H_2O + heat$$

The heat energy thus produced is used to meet needs of energy in homes, transportation, as well as in industries.

Hydrocarbons as Feed Stock in Industry

Hydrocarbons are not only used as fuel in automobiles or industries, they also act as raw materials in many industries.

(i) Petrochemical Industry:

The organic compounds prepared from hydrocarbons (petroleum and natural gas) are called petrochemicals. Some of the important petrochemicals are, methyl alcohol, ethyl alcohol, formic acid, chloroform, carbon tetrachloride, ethylene, butadiene, benzene, toluene, etc.

(ii) Plastic Industry:

Hydrocarbons are used as raw materials for the preparation of a large variety of synthetic polymers, called plastics like polythene, polyester. These can be given any shape when soft, and on hardening make a durable article to be used in common life. For example, crockery items (cups, glass, jug, plates, spoons) furniture items (chair, table, stool) automobile parts, electric and sewages items and a lot of other household items.

(iii) Rubber Industry:

Hydrocarbons are used to prepare synthetic rubber. Such as, acetylene is used to prepare butadiene rubber used for making footwear, tyres and toys. Similarly, a good quality rubber neoprene is prepared from chloroprene.

(iv) Synthetic fibre Industry:

Hydrocarbons are used to prepare synthetic fibres like nylon, rayon, polyesters. These fibres have better qualities like greater strength, good elasticity, resistance to wear and tear. So clothes made of synthetic fibres are long lasting than that of natural fibres.

(v) Synthetic detergents:

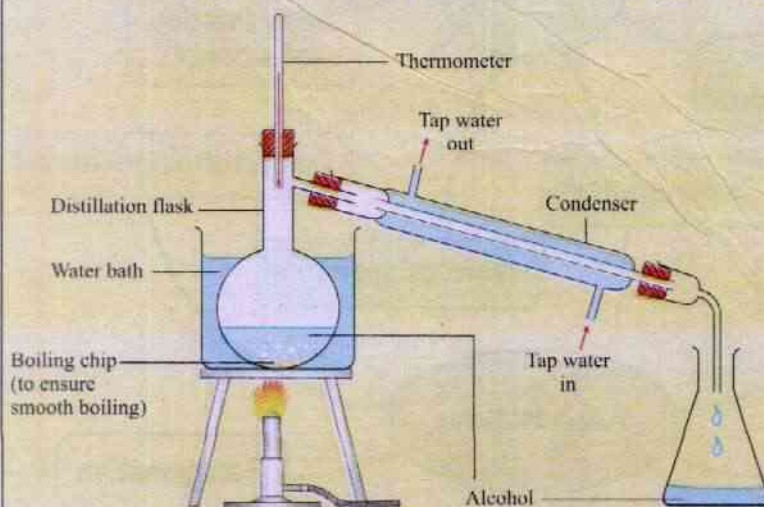
Long chain hydrocarbons obtained from petroleum are used to make synthetic detergents and washing powders. These detergents are sodium salts of alkyl hydrogen sulphate. These detergents have better and stronger cleaning properties than that of soaps. They can be used even in hard water.

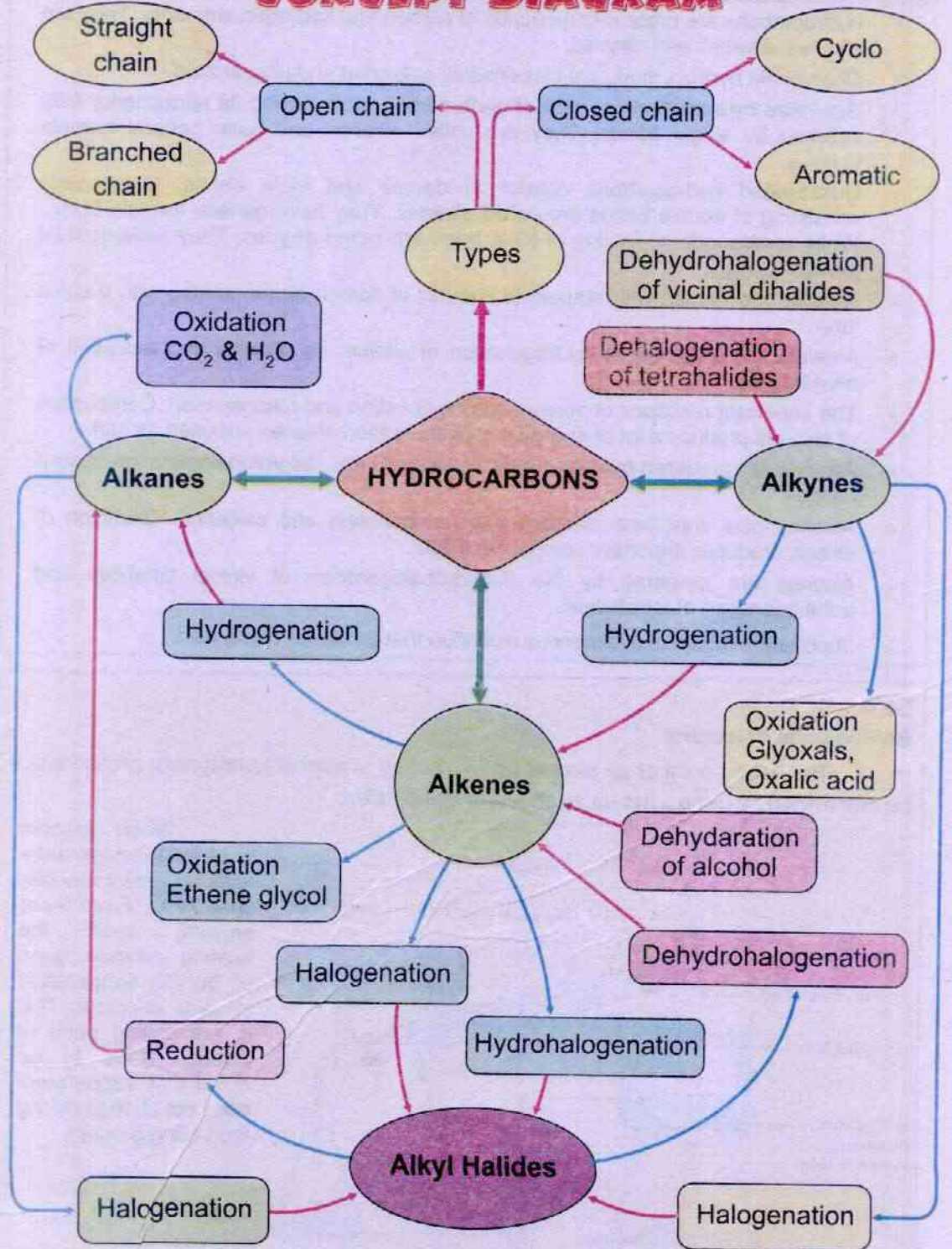
Key Points

- Hydrocarbons are organic compounds of carbon and hydrogen elements. They are alkanes, alkenes and alkynes.
- Open chain hydrocarbons are classified as saturated and unsaturated.
- Saturated hydrocarbons consist of each carbon atom having its tetravalency fully satisfied by single bonds. They are called alkanes and have general formula C_nH_{2n+2}.
- Unsaturated hydrocarbons consist of double and triple bonds. Compounds consisting of double bonds are called alkenes. They have general formula C_nH_{2n}. While compounds consisting of triple bond are called alkynes. They have general formula C_nH_{2n-2}.
- Alkanes are named with respect to number of carbon atoms ending with a suffix 'ane'.
- Alkanes are prepared by hydrogenation of alkenes or alkynes and reduction of alkyl halides.
- The important reactions of alkanes are combustion and halogenation. Combustion of alkanes produce a lot of energy that is the reason alkanes are used as fuel.
- Alkenes are prepared by dehydration of alcohols and dehydrohalogenation of alkyl halides.
- Alkenes give important reactions like halogenation and oxidation. Oxidation of alkene produces important compound, glycol.
- Alkynes are prepared by the dehydrohalogenation of vicinal dihalides and dehalogenation of tetrahalides.
- Important reaction of acetylene is oxidation that produces oxalic acid.

SKILLS:

Boiling point of alcohol

The boiling point of an alcohol (ethyl alcohol) at normal atmospheric pressure can be determined by using a set up as shown in figure below.

When alcohol is heated, temperature rises up until it reaches upto 78°C. From there onward, even the heating process goes on but the temperature remains constant. This is the boiling point of alcohol. It is to be noted that temperature does not change during the boiling process.

CONCEPT DIAGRAM

EXERCISE

Multiple Choice Questions

Put a (✓)on the correct answer

1. **Which one of these hydrocarbon molecules would have no effect on an aqueous solution of bromine?**
   a. CH_4 b. $C_{10}H_{20}$
   c. C_2H_4 d. C_2H_2

2. **If an organic compound has 4 carbon atoms, all singly bonded, it will have the following characteristics except one**
   a. it will be saturated hydrocarbon.
   b. it will have 8 hydrogen atoms.
   c. its name will be n-butane.
   d. it will be least reactive.

3. **The reduction of alkyl halides takes place in the presence of**
   a. Zn/HCl b. Na/HCl
   c. Mg/HCl d. Cu/HCl

4. **Halogenation of methane does not produce which one of the following:**
   a. carbon tetrachloride b. chloroform
   c. carbon black d. chloromethane

5. **Incomplete combustion of alkanes produces**
   a. carbon dioxide only
   b. carbon monoxide only
   c. carbon monoxide and carbon black
   d. carbon dioxide and carbon black

6. **Alkenes are prepared from alcohols by a process called**
   a. dehydrogenation b. dehalogenation
   c. dehydration d. dehydrohalogenation

7. **Dehydrohalogenation takes place in the presence of**
   a. NaOH aqueous b. alcoholic KOH
   c. aqueous KOH d. alcoholic NaOH

8. **Oxidation of ethene with $KMnO_4$ produces**
   a. oxalic acid b. glyoxal
   c. ethane glycol d. propene glycol

9. **Which one of these is a saturated hydrocarbon?**

a. C_2H_4 b. C_3H_6
c. C_4H_8 d. C_5H_{12}

10. **A hydrocarbon has molecular formula C_8H_{14}. What is the molecular formula of the next member of the same homologous series?**

a. C_9H_{18} b. C_9H_{16}
c. C_9H_{20} d. C_9H_{12}

11. **What is the molecular formula for the eighth alkane member, octane, which is found in petrol?**

a. C_8H_8 b. C_8H_{16}
c. C_8H_{18} d. C_8H_{20}

12. **One of the hydrocarbons reacts with one mole of hydrogen to form a saturated hydrocarbon. What is the formula could be of the X?**

a. C_3H_8 b. C_6H_{12}
c. C_4H_{10} d. C_7H_{16}

13. **Dehydration of alcohols can be carried out with:**

a. NaOH b. KOH
c. H_2SO_4 d. HCl

14. **The end product of oxidation of acetylene is:**

a. oxalic acid b. glycol
c. glyoxal d. none of these

15. **Dehalogenation of tetrahalides produces acetylene. This reaction takes place in the presence of:**

a. sodium metal b. zinc metal
c. magnesium metal d. potassium metal

16. **Substitution reaction is the characteristics of:**

a. alkanes b. alkenes
c. alkynes d. none of these

17. **Halogenation of methane in the presence of diffused sunlight takes place:**

a. suddenly, only in one step b. slowly in one step
c. in a series of four steps d. fastly in two steps

18. **Which one of the followings is a substitution reaction?**
   a. halogenation of alkynes
   b. halogenation of alkenes
   c. halogenation of alkanes
   d. bromination of alkenes

19. **The order of reactivity of hydrogen halides with alkenes is**
   a. HI > HBr
   b. HBr > HI
   c. HCl > HBr
   d. HBr < HCl

20. **Oxidation of alkenes produce**
   a. glyoxal
   b. glycol
   c. oxalic acid
   d. formic acid

Short Questions

1. Differentiate between saturated and unsaturated hydrocarbons.
2. A compound consisting of four carbon atoms has a triple bond in it. How many hydrogen atoms are present in it?
3. Why are the alkanes called 'paraffins'?
4. What do you know about hydrogenation of alkenes?
5. How are alkyl halides reduced?
6. Why are the alkanes used as fuel?
7. How can you prepare ethene from alcohol and ethyl bromide?
8. Identify propane from propene with a chemical test.
9. Why are the alkenes called 'olefins'?
10. Why alkane can't be oxidized with $KMnO_4$ solution?
11. What are the addition reactions? Explain with an example.
12. Justify that alkanes give substitution reactions.
13. Both alkenes and alkynes are unsaturated hydrocarbons. State the one most significant difference between them.
14. Write the molecular, dot and cross and structural formule of ethyne.
15. Why hydrocarbons are soluble in organic solvents?
16. Give the physical properties of alkanes.
17. How can you identify ethane from ethene?
18. Why colour of bromine water discharges on addition of ethene in it?
19. State one important use of each:
   (i) Ethene
   (ii) Acetylene
   (iii) Chloroform
   (iv) Carbon tetrachloride

Estensive Questions

1. What type of reactions are given by alkanes? Explain with reference to halogenations of alkanes.
2. Alkanes are a source of heat. Explain it.
3. Prepare the following as directed:

   a. ethane from ethene;

   b. acetylene from tetrahalide;

   c. carbon tetracholride from methane;

   d. ethylene glycol from ethene;

   e. 1,2-dibromoethane from ethene and

   f. glyoxal from acetylene
4. Explain the oxidation of acetylene.
5. Write balanced chemical equations for the following reactions. Also name the products that formed.

   (i) A mixture of ethyne and hydrogen is passed over heated nickel

   (ii) Ethyne is treated with chlorine

   (iii) Ethyne is burnt in air

   (iv) Ethyne is passed through bromine water
6. Explain briefly:

   (i) Why butane undergoes substitution reactions?

   (ii) There are millions of organic compounds.

   (iii) Acetylene undergoes addition reactions in two stages.

   (iv) Alkynes are more reactive than alkanes.

Chapter 13

Biochemistry

Major Topics

13.1 Carbohydrates
13.2 Proteins
13.3 Lipids
13.4 Nucleic acids
13.5 Vitamins

Time allocation

Teaching periods	15
Assessment periods	03
Weightage	6%

Students Learning Outcomes

Students will be able to:

- distinguish between mono-, di-and trisaccharides. (Understanding);
- describe the bonding in a protein. (Understanding);
- explain the sources and uses of carbohydrates, proteins and lipids. (Understanding);
- differentiate between fats and oils. (Applying);
- describe the importance of nucleic acids. (Understanding) and
- define and explain vitamins and their importance. (Understanding).

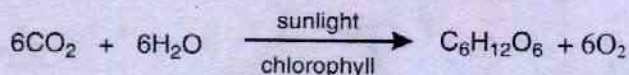
Introduction

Biochemistry is a field that has a great importance today. It deals with the naturally occurring macromolecules such as carbohydrates, proteins, lipids, nucleic acids and vitamins. These macromolecules are synthesized by living organisms from simple molecules present in the environment. Macromolecules are essential for us as they are reservoirs of energy. For example, carbohydrates we eat, provide us energy. Lipids are major source of energy. They are stored in the body to provide emergency energy supplies. They help us to work during tough times. Proteins not only provide us energy, they help us stay strong by forming new bones and muscular tissues. Moreover, proteins protect us against the diseases. Nucleic acids are responsible for transmitting genetic information from generation to generation.

13.1 CARBOHYDRATES

Carbohydrates are macromolecules defined as polyhydroxy aldehydes or ketones. They have general formula $C_n(H_2O)_n$.

Carbohydrates are synthesized by plants through photosynthesis process from carbon dioxide and water in the presence of sunlight and green pigment chlorophyll.

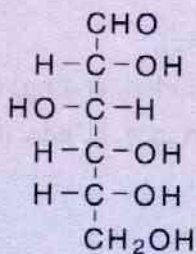
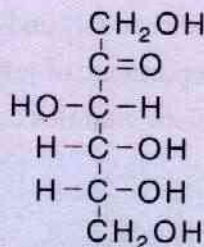
$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

The glucose is further polymerized to form starch and cellulose.

Carbohydrates are classified as

i. Monosaccharides
ii. Oligosaccharides
iii. Polysaccharides

13.1.1 Monosaccharides

Monosaccharides are the simplest sugars which cannot be hydrolyzed. They consist of 3 to 9 carbon atoms. Therefore, they are classified according to the number of carbon atoms in their molecules as trioses, tetroses, pentoses, hexoses, and so on. The important monosaccharides are hexoses like glucose and fructose, etc. Glucose is a pentahydroxy aldehyde while fructose is pentahydroxy ketone having the open chain structures as follows and general formula $C_6H_{12}O_6$.

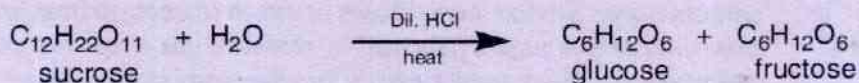
```
      CHO                 CH2OH
       |                    |
   H - C - OH               C=O
       |                    |
  HO - C - H           HO - C - H
       |                    |
   H - C - OH           H - C - OH
       |                    |
   H - C - OH           H - C - OH
       |                    |
      CH2OH                CH2OH
```

Glucose   Fructose

Monosaccharides are white crystalline solids. They are soluble in water and have sweet taste. They cannot be hydrolyzed. They are reducing in nature, therefore, these are called reducing sugars.

13.1.2 Oligosaccharides

Oligosaccharides give 2 to 9 units of monosaccharides on hydrolysis. Therefore, they are classified as disaccharides, trisaccharides, tetrasaccharides, etc., depending upon the number of units they produce on hydrolysis. The most important

oligosaccharides are disaccharides like sucrose. On hydrolysis, sucrose produces one unit of glucose and one unit of fructose.

$$\underset{\text{sucrose}}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow[\text{heat}]{\text{Dil. HCl}} \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{fructose}}{C_6H_{12}O_6}$$

These carbohydrates are white, crystalline solids easily soluble in water. They are also sweet in taste. They may be reducing or non-reducing.

13.1.3 Polysaccharides

Polysaccharides are macromolecular carbohydrates consisting of hundreds to thousands of monosaccharides. Examples of polysaccharides are starch and cellulose. They are amorphous solids. They are tasteless and insoluble in water. They are non reducing in nature.

13.1.4 Sources and Uses of Carbohydrates

Carbohydrates range from simple to complex ones. They have varied sources and uses. Sources of simple sugars e.g. glucose, fructose and galactose are fruits, vegetables, honey and cereals.

Disaccharides are sucrose, lactose and maltose. Sucrose is found in sugar beet, sugar cane and fruits.

Lactose consisting of glucose and galactose is the main sugar in milk and dairy products.

Maltose, a disaccharide of two glucose molecules is found in cereals.

Polysaccharides are starch and cellulose. Starch is found in cereal crops; wheat, barley, maize, rice, etc. Cotton is pure cellulose.

Our body uses carbohydrates in the form of glucose. Glucose is the only form of carbohydrates that is used directly by muscles for energy. It is important to note that brain needs glucose as an energy source, because it cannot use fat for this purpose.

Besides, the energy providing materials, carbohydrates also provide the following usage to our body.

(i) They regulate the amount of sugar level in our body. Low sugar level in body results in hypoglycemia.

(ii) They provide essential nutrients for bacteria in intestinal tract that helps in digestion.

(iii) Dietary fibre helps to keep the bowel functioning properly.

(iv) Fibre helps in lowering of cholesterol level and regulates blood pressure.

(v) Carbohydrates protect our muscles from cramping.

Carbohydrates as source of energy:

Carbohydrates provide 17 kilojoules of energy per gram. We take carbohydrates as food. Long chains of starch (carbohydrates) are broken down into simple sugars (glucose) by digestive enzymes. The glucose is absorbed directly by small intestine into the blood stream. Blood stream transports the glucose to its place of use, e.g., muscles.

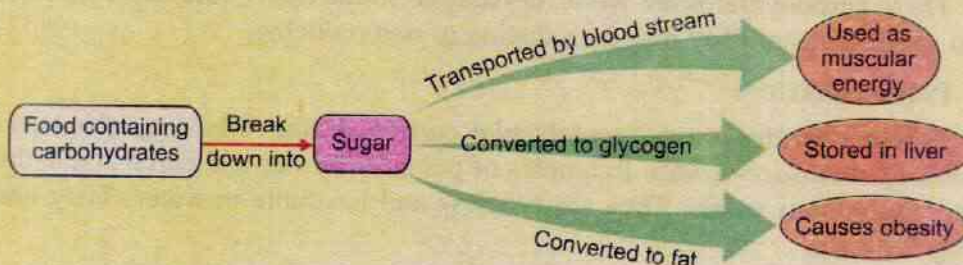



Fig. 13.1 Showing carbohydrates as a source of energy.

i. Define carbohydrates.
ii. Give the characteristics of disaccharides.
iii. Give the balanced equation for the formation of glucose.
iv. Draw the structure of glucose.
v. Give the balanced equation for the hydrolysis of sucrose.

The use of dextrose in drips:

Dextrose is crystallized glucose (natural sugar found in starchy foods). It provides simple carbohydrates to the body that can be easily broken down and processed. Dextrose solution is available in several concentrations. For example, five percent dextrose solution (D5W) consists of 5 grams of dextrose in each 100 mL of solution. It is used to provide fluid replacement and energy to the body. It contains approximately 170 calories of energy, but does not contain electrolytes. Therefore, electrolytes are added according to requirements in solution. Dextrose is given to patients directly into vein called intravenous (IV) therapy. It is commonly called drip system. It is the fastest way to deliver fluids, electrolytes and medications throughout the body. It prevents air entering into blood stream.

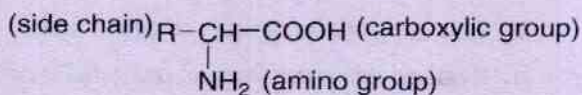
13.2 PROTEIN

Proteins are highly complicated nitrogenous compounds made up of amino acids. Proteins consist of carbon, hydrogen, oxygen, nitrogen and sulphur. They are polymers of amino acids. Amino acids are linked with each other through peptide linkage ($-\overset{O}{\overset{\|}{C}}-NH-$). Protein has more than 10,000 amino acids. All proteins yield amino acids upon hydrolysis.

Proteins are present in all living organisms. They make up bulk of the non-bony structure of the animal bodies. They are major component of all cells and tissues of animals. About 50% of the dry weight of cell is made up of proteins. They are found in muscles, skin, hair, nails, wool, feathers, etc.

Amino acids

Amino acids are organic compounds consisting of both amino and carboxyl groups. They have the general formula:

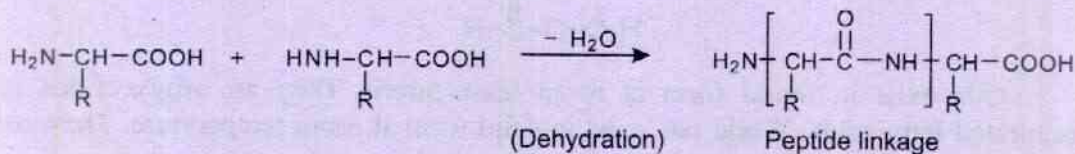
$$\text{(side chain)}\ R-\underset{\underset{NH_2\ \text{(amino group)}}{|}}{CH}-COOH\ \text{(carboxylic group)}$$

Side chain 'R' is different for different amino acids. There are 20 amino acids.

Ten out of twenty amino acids can be synthesized by human body. These amino acids are called *non-essential amino acids*. While the other ten which cannot be synthesized by our bodies are called *essential amino acids*. Essential amino acids are required by our bodies and must be supplied through diet.

13.2.1 Amino acids are Building Blocks of Proteins:

Two amino acids link through peptide linkage. Peptide linkage (bond) is formed by the elimination of water molecule between the amino group of one amino acid and carboxyl acid group of another, such as:

$$H_2N-\underset{R}{\underset{|}{CH}}-COOH \;+\; HNH-\underset{R}{\underset{|}{CH}}-COOH \xrightarrow[\text{(Dehydration)}]{-\,H_2O} H_2N\left[CH(R)-\overset{O}{\overset{||}{C}}-NH\right]-\underset{R}{\underset{|}{CH}}-COOH$$

Peptide linkage

When thousands of amino acids polymerize they form protein.

13.2.2 Sources and Uses of Proteins:

Proteins make up more than 50% of the dry weight of animals. Each protein has its source and carries out a specific function. Sources and uses of protein are as follows:

(i) Sources of animal's proteins are meat, mutton, chicken, fish, eggs. These are used as food by human beings as they are essential for the formation of protoplasm.

(ii) Enzymes are proteins that are produced by the living cells. They catalyze the chemical reactions taking place in the bodies. They are highly specific and have extraordinary efficiency. Many enzymes are used as drugs. They control the bleeding and treat blood cancer.

(iii) Hides are proteins. These are used to make leather by tanning. Leather is used to make shoes, jackets, sports items, etc.

(iv) Proteins are found in bones. When bones are heated they give gelatin. Gelatin is used to make bakery items.

(v) Plants also synthesize proteins, such as pulses, beans, etc. These are used as food.

Test yourself 13.2

i. Which elements are found in proteins?

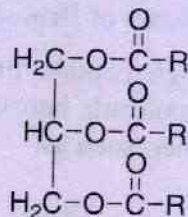
ii. How amino acids are bonded with each other?

iii. Give the general formula of amino acid.

iv. What do you mean by non-essential amino acids?

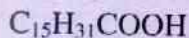
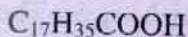
13.3 LIPIDS

Lipids are macromolecules made up of fatty acids. Lipids include oils and fats. Oils and fats are esters of long chain carboxylic (fatty) acids with glycerol. These esters are made of three fatty acids, therefore, they are called triglycerides. General formula of triglycerides is as under.

$$\begin{array}{l} H_2C-O-\overset{\displaystyle O}{\overset{\|}{C}}-R \\ \;\;| \\ HC-O-\overset{\displaystyle O}{\overset{\|}{C}}-R \\ \;\;| \\ H_2C-O-\overset{\displaystyle O}{\overset{\|}{C}}-R \end{array}$$

Oils exist in liquid form at room temperature. They are triglycerides of unsaturated fatty acids. While fats exist in solid form at room temperature. They are triglycerides of saturated fatty acids.

13.3.1 Fatty Acids

Fatty acids are building blocks of lipids. They are long chain saturated or unsaturated carboxylic acids. Examples are:

$C_{15}H_{31}COOH$ Palmitic acid

$C_{17}H_{35}COOH$ Stearic acid

These acids form esters (oils or fats) with glycerol in the presence of mineral acids.

13.3.2 Sources and Uses of Lipids

Fats and oils are high energy foods. They are source of vitamins A, D and E. They are used to build brain cells, nerve cells and cell membranes. They are insoluble in water but soluble in organic solvents. The fats stored in the body insulate it as they are poor conductor of heat and electricity.

Fats and oils are synthesized naturally by animals, plants and marine organisms.

(i) Animal fats are found in adipose tissue cells. Animals secrete milk from which butter and ghee is obtained. Butter and ghee are used for cooking and frying of food, for preparing bakery products and sweets.

(ii) Animal fats are used in soap industry.

(iii) Plants synthesize oils and store them in seeds, such as sunflower oil, coconut oil, groundnut oil and corn oil. These oils are used as vegetable oils or ghee for cooking and other purposes.

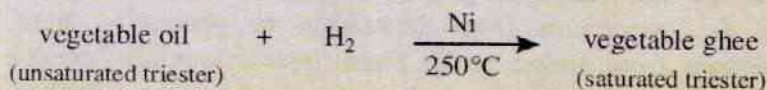
(iv) Marine animals like salmon and whales are also source of oils. These oils are used as medicines, e.g. cod liver oil.

Test yourself 13.3

i. What is difference between ghee and oil?
ii. Give the characteristics of fats.
iii. Give the sources and uses of animal fats.
iv. Plants are source of oils, justify.

Hydrogenation of vegetable oil:

Vegetable oils are triester of glycerol and fatty acids of unsaturated long chains. These oils are hydrogenated in the presence of nickel catalyst at 250 to 300 °C to form vegetable ghee.

$$\underset{\text{(unsaturated triester)}}{\text{vegetable oil}} + H_2 \xrightarrow[250^\circ C]{Ni} \underset{\text{(saturated triester)}}{\text{vegetable ghee}}$$

Interesting Information

Margarine is produced by adding hydrogen to vegetable oil at 200 °C in the presence of catalyst. Greater the amount of hydrogen added, the more solid the margarine becomes.

Interesting Information

Rancid butter has a foul smell because of butanoic acid. However, the esters of butanoic acid have fruity smell. For example, methyl butanoate smells like apples and ethyl butanoate smells like pineapple.

13.4 NUCLEIC ACIDS

Nucleic acids are essential components of every living cell. They are generally long chain molecules made up of nucleotides. Each nucleotide consists of three components; nitrogenous base, a pentose sugar and a phosphate group.

There are two types of nucleic acids:

13.4.1 Deoxyribonucleic Acid (DNA)

DNA consists of deoxyribose sugar. Its structure was discovered by J. Watson and F. Crick in 1953. It is long double stranded molecule consisting of two chains. Each chain is made up of sugar, phosphate and a base. The sugar and phosphate groups make the backbone of the chains and two chains are linked through bases. The chains are wrapped around each other in a double helix form as shown in figure 13.2.

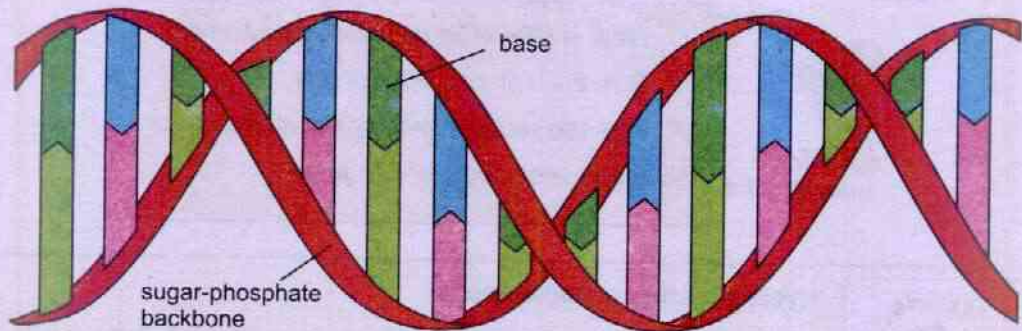



Fig. 13.2 DNA Structure

DNA is the permanent storage place for genetic information in the nucleus of a cell. It carries and stores all genetic informations of the cell. It passes these informations as instructions from generation to generation how to synthesize particular proteins from amino acids. These instructions are 'genetic code of life'. They determine whether an organism is a man or a tree or a donkey and whether a cell is a nerve cell or a muscle cell.

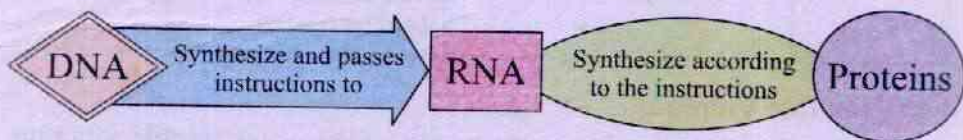
The sequence of nitrogenous bases in DNA determines the protein development in new cells. The function of the double helix formation of DNA is to ensure that no disorder takes place. DNA carries genes that controls the synthesis of RNA. Errors introduced into the genes synthesize faulty RNA. It synthesizes faulty proteins that do not function the way they are supposed to. This disorder causes genetic diseases.

13.4.2 Ribonucleic acid (RNA)

It consists of ribose sugar. It is a single stranded molecule. It is responsible for putting the genetic information to work in the cell to build proteins. Its role is like a messenger.

RNA is synthesized by DNA to transmit the genetic information. RNA receives, reads, decodes and uses the given information to synthesize new proteins. Thus RNA is responsible for directing the synthesis of new proteins.

Interesting Information

Cancer is caused by damage to DNA or interfering with the mechanism of its replication or passing informations. So, by understanding the mechanism of action of DNA, cancer can be cured.

13.5 VITAMINS

In 1912 Hopkins noticed that in addition to carbohydrates, proteins and fats there are other substances needed for normal growth. Although these substances were needed in small quantity, yet these substances were called Accessory Growth Factors. Later Funk proposed the name `Vitamin` for these substances. He discovered Vitamin B_1 (Thiamin).

13.5.1 Types of Vitamins

Vitamins are divided into two types:

(i) Fat Soluble Vitamins

The vitamins which dissolve in fats are called fat soluble vitamins. These are vitamin A, D, E and K. If these vitamins are taken in large quantity, they accumulate in the body and cause diseases. For example, accumulation of vitamin D in the body causes bone-pain and bone-like deposits in the kidney. However, their deficiency also causes diseases. Sources, uses and diseases because of deficiency are provided in the Table 13.1.

Table 13.1: Sources, uses and diseases due to deficiency of some fat soluble vitamins.

No.	Vitamin	Sources	Uses	Diseases
i	Vitamin A	Dairy products, eggs, oils and fats, fish. It can also be obtained from the beta-carotene found in green vegetables, carrots and liver.	Maintains the health of the epithelium and acts on the retina's dark adaptation mechanism.	Night blindness, eye inflammation.
ii	Vitamin D	Fish liver, dairy products, oils and fats. Vitamin D is formed in the skin when it is exposed to sunlight.	Has a role in the absorption of calcium, which is essential for the maintenance of healthy bones.	Rickets

(ii) Water Soluble Vitamins

The vitamins that dissolve in water are called water soluble vitamins. These vitamins are B complex (this include 10 vitamins) and vitamin C (ascorbic acid). Water soluble vitamins are rapidly excreted from the body. Hence, these vitamins are not toxic even if taken in large quantity. However, their deficiency causes disease.

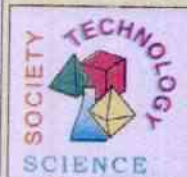
13.5.2 Importance of Vitamins

(i) Each vitamin plays an important role in the healthy development of our body.

(ii) Natural vitamins are organic food substances found only in plants and animals. Our body is unable to synthesize vitamins. Because of this, they must be supplied either directly in the diet or by way of dietary supplements. They are absolutely necessary for our normal growth.

(iii) Vitamins cannot be assimilated without ingesting food. This is why, it is suggested that vitamins must be taken with meal. They help to regulate our body's metabolism.

Test yourself 13.4

i. What are the disadvantages of fats soluble vitamins?
ii. What are advantages of water soluble vitamins?
iii. Give examples of fats soluble vitamins.
iv. What are the components of nucleotide?
v. What is the function of DNA?
vi. Why RNA is called a messenger?

Commercial uses of enzymes.

Enzymes are used on commercial scale for different purposes. Common types of enzymes and their role in industry is described as:

(i) Enzymes present in the yeast are commercially used for the fermentation of molasses and starch to produce alcohol (Ethanol).These enzymes are diastase, invertase and zymase.

(ii) Microbial enzymes are used in detergents (powder or liquid). Lipases decompose fats into more water soluble compounds. Amylase removes starch based stains. Cellulase degrades cellulose to glucose, a water soluble compound. Bacterial proteases break down protein stains on the clothes. Thus, enzymes containing detergents clean effectively and remove all stains and dirt.

(iii) Enzymes are used for the purification of fruit juices. They are added to fruit that has been crushed like grapes. This increases the yield of the juice extracted by removing suspended particles. It also improves the colour derived from the fruit skins.

(iv) Amylase enzymes are used in bread making because they can yield more starch of the flour. Even they are efficient enough to convert starch to sweet glucose syrup. This can be used as sweetner in the food as well as bread making.

(v) Lactase enzyme is used to increase sweetness in ice cream. As lactose in milk is broken down to galactose and glucose, which are sweeter than lactose.

(vi) In the dairy industry some enzymes are used for the production of cheeses, yogurt and other dairy products while others are used to improve texture or flavours of the products.

Key Points

- Carbohydrates are polyhydroxy aldehydes or ketones. They are classified as monosaccharides, oligosaccharides and polysaccharides.
- Monosaccharides are unhydrolyzable consisting of 3 to 9 carbon atoms. They are sweet, crystalline solids soluble in water.
- Oligosaccharides hydrolyze to give 2 to 9 units of monosaccharides. They are also sweet, crystalline solids soluble in water.
- Polysaccharides consist of hundreds to thousands of monosaccharides. They are tasteless, amorphous solids insoluble in water.
- Carbohydrates are naturally synthesized macromolecules. They are found in fruits, vegetables, cereal foods and milk.
- Carbohydrates are main source of energy.

- Proteins are nitrogenous compounds made up of amino acids. Thousands of amino acids are bonded through peptide linkage to form proteins.
- Sources of animal proteins are meat, butter, chicken, fish and eggs.
- Proteins are used by human beings as they are essential to form protoplasm.
- Lipids are macromolecules made up of fatty acids. They are oils and fats.
- Fatty acids are long chain saturated or unsaturated carboxylic acids.
- Lipids are high energy compounds. They are synthesized naturally by animals, plants and microorganisms.
- Nucleic acids are long chain molecules made up of nucleotides.
- Deoxyribonucleic acid (DNA) is a long double stranded molecule and is responsible for transmitting genetic information to next generations.
- Ribonucleic acid (RNA) is a single stranded molecule. It is responsible for formation of proteins.
- Vitamins are necessary growth factors. They are divided into two types:

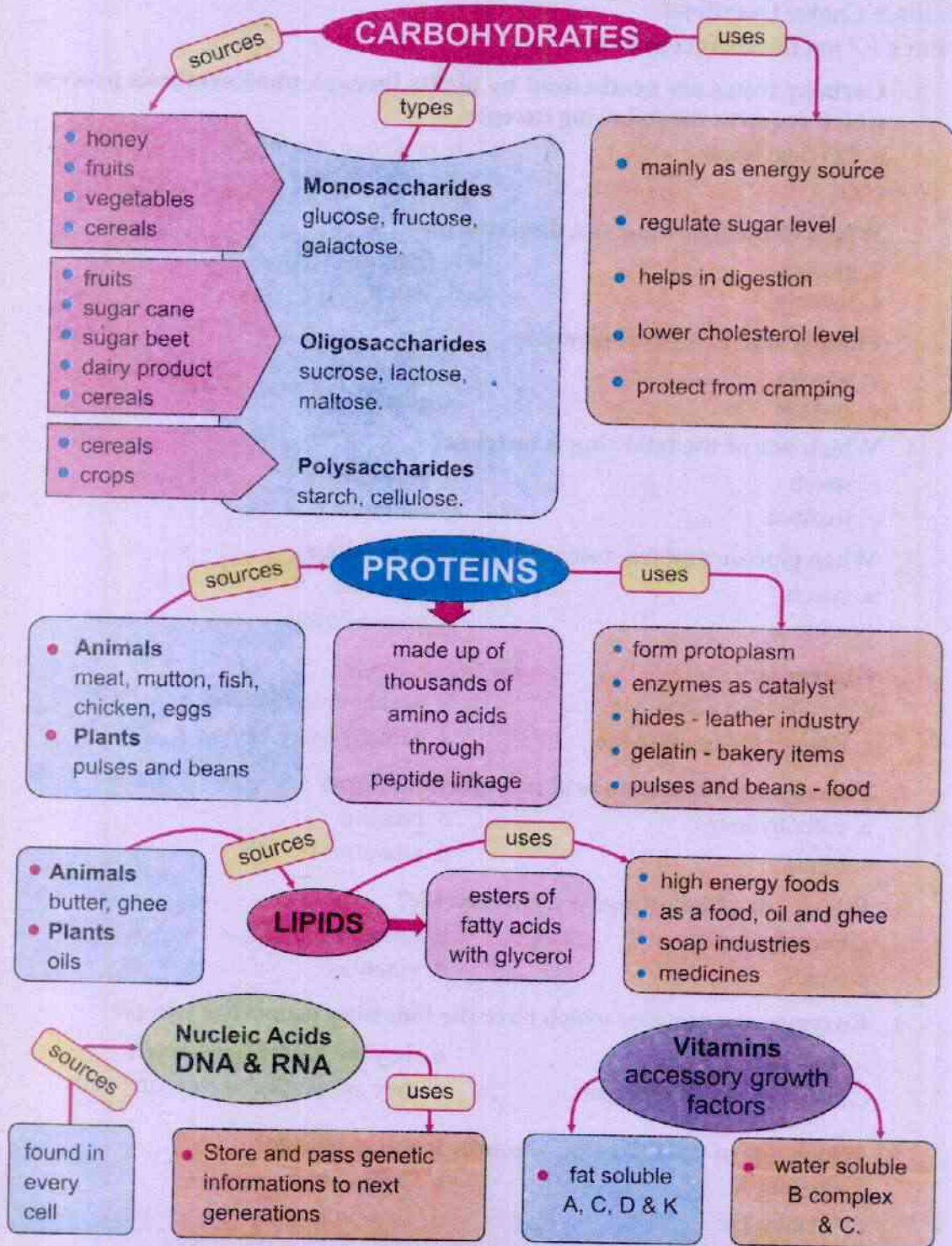
  Fat soluble (A, D, E and K) and water soluble vitamins (B complex and vitamin C).
- Vitamins play a significant role for proper growth and development of our body.

SKILLS

Solubility of starch and sugar: solubility of starch and sugar in water can be checked in laboratory as well as at home. Starch is insoluble in water while sugar is soluble in water forming a clear solution in water.

Denaturing of Protein

Denaturing of protein means precipitation or coagulation of protein. It can be carried out by heating or changing pH. A simple common method for denaturing of protein is boiling of an egg. White viscous fluid (albumen) present in an egg is protein. When egg is boiled for a few minutes, albumen coagulates i.e., solidifies.

CONCEPT DIAGRAM

EXERCISE

Multiple Choice Questions

Put a (✓)on the correct answer

1. **Carbohydrates are synthesized by plants through photosynthesis process which requires the following except:**

a. CO_2 and water
b. presence of sunlight
c. O_2
d. chlorophyll

2. **Which of the following is a disaccharide?**

a. glucose
b. fructose
c. sucrose
d. starch

3. **Photosynthesis process produces**

a. starch
b. cellulose
c. sucrose
d. glucose

4. **Which one of the following is tasteless?**

a. starch
b. glucose
c. fructose
d. sucrose

5. **When glucose and fructose combine they produce:**

a. starch
b. cellulose
c. sucrose
d. none of these

6. **Glucose is:**

a. hexahydroxy aldehyde
b. hexahydroxy ketone
c. pentahydroxy aldehyde
d. pentahydroxy ketone

7. **Thousand of the amino acid polymerize to form**

a. carbohydrates
b. proteins
c. lipids
d. vitamins

8. **Which one of followings is a triglyceride?**

a. carbohydrates
b. proteins
c. lipids
d. vitamins

9. **Enzymes are proteins which have the following properties except:**

a. they catalyze reaction
b. they are highly non-specific
c. they are highly efficient
d. they are produced by living cells

10. **Which one of the following vitamins is water soluble?**

a. vitamin A
b. vitamin C
c. vitamin D
d. vitamin E

11. Which one of the following is a fat soluble vitamin?

a. A
b. E
c. K
d. All of these

12. Which one of the following is not the characteristics of monosaccharide?

a. white crystalline solids
b. soluble in water
c. hydrolysable
d. reducing in nature

13. Which one of the following statements about glucose and sucrose is incorrect?

a. soluble in water
b. naturally occurring
c. carbohydrates
d. disaccharides

14. Which one of the following is a reducing sugar?

a. glucose
b. maltose
c. sucrose
d. starch

15. The most important oligosaccharide is:

a. sucrose
b. glucose
c. fructose
d. maltose

16. Night blindness is because of deficiency of:

a. vitamin A
b. vitamin E
c. vitamin C
d. vitamin D

17. The organic compounds used as drugs to control bleeding are:

a. vitamins
b. proteins
c. lipids
d. glycerides

18. Deficiency of Vitamin E causes

a. rickets
b. scurvy
c. anemia in babies
d. night blindness

19. Lipids are macromolecules. They have characteristics except one of the following:

a. they are high energy foods
b. they are soluble in water
c. they are poor conductor of heat
d. they are esters of fatty acids

20. Vitamins are Accessory Growth Factors. They play important role in our body like:

a. provide energy to the body
b. insulate our body from electric shock
c. build brain cells
d. regulate metabolic process

Short Answer Questions

1. How Plants synthesize carbohydrates?
2. Give the characteristics of monosaccharides.
3. What is difference between glucose and fructose?
4. Give an example of a disaccharide. How it is hydrolyzed into monosaccharides?
5. Give the characteristics of polysaccharides.
6. Where are the proteins found?
7. Describe the uses of carbohydrates.
8. Lactose is disaccharide; which monosaccharide are present in it?
9. Why the ten amino acids are essential for us?
10. How are proteins formed?
11. How is gelatin obtained?
12. Give the general formula of the lipids.
13. Name two fatty acids with their formulae.
14. Give the types of vitamins.
15. What is the significance of vitamins?
16. Describe the sources and uses of vitamin A.
17. Justify water soluble vitamins are not injurious to health.
18. What do you mean by genetic code of life?
19. What is the function of DNA?
20. How you justify RNA works like a messenger?

Long Answer Questions

1. What are carbohydrates? How monosaccharides are prepared? Give their characteristics.
2. Explain oligosaccharides.
3. What are polysaccharides? Give their properties.
4. Explain the sources and uses of proteins.
5. Explain that amino acids are building blocks of proteins.
6. Explain the sources and uses of lipids.
7. Give the importance of vitamins.
8. Describe the sources, uses and deficiency symptoms of water soluble vitamins.

Chapter 14

Environmental Chemistry I

The Atmosphere

Major Topics

Time allocation	
Teaching periods	10
Assessment periods	02
Weightage	7%

Students Learning Outcomes

Students will be able to:

- define atmosphere. (Remembering);
- explain composition of atmosphere. (Understanding);
- differentiate between stratosphere and troposphere. (Analyzing);
- summarize the compounds of stratosphere and troposphere. (Understanding);
- describe major air pollutants.(Understanding);
- describe sources and effects of air pollutants. (Understanding);
- explain ozone formation. (Understanding);
- describe acid rain and its effects (Understanding);
- describe ozone depletion and its effects. (Understanding);
- describe global warming. (Understanding).

Introduction

Our planet the Earth has four natural systems; lithosphere, hydrosphere, atmosphere and biosphere. The knowledge and understanding of these systems is necessary for us to live on the Earth.

In this chapter, we will focus only on atmosphere. The study of composition of atmosphere provides us the knowledge about significance of gases present in the atmosphere. Atmosphere is divided into four regions. Each region has its natural characteristics. But human activities are disturbing the natural system. Because of these activities our atmosphere is gradually changing. The effects of these changes will be discussed in this chapter. A lot of efforts are being made worldwide to control the negative effects of pollution.

14.1 COMPOSITION OF ATMOSPHERE

Atmosphere is the envelope of different gases around the Earth. It extends continuously from the Earth's surface outwards without any boundary. About 99% of atmospheric mass lies within 30 kilometres of the surface and 75% lies within the lowest 11 kilometres.

Percentage composition of atmosphere by volume is shown in Table 14.1.

Table 14.1 Composition of dry air

Gas	% by Volume
Nitrogen	78.09
Oxygen	20.94
Argon	0.93
Carbon dioxide	0.03

Do you know

- *Sunlight has short wavelength radiations.*
- *Solar energy absorbed by the Earth surface is transformed into heat energy which is of longer wavelength.*
- *On the average there is total 32% reflection of light: 6% being reflected from the Earth's surface and 26% being reflected back into space because of clouds, gases and dust particles in the atmosphere.*
- *18% of sunlight is absorbed by atmospheric gases.*
- *The remaining 50% reaches upto the Earth and is absorbed by it. This energy is radiated as heat energy of longer wavelength which is absorbed by water vapours and CO_2 in atmosphere.*

14.2 LAYERS OF ATMOSPHERE

Atmosphere consists of four spheres (layers) extending from the surface of the Earth upwards. The concentration of the component gases decreases gradually upwards, that results in gradual decrease of pressure. But temperature of the atmosphere does not change in a gradual way. It varies in a complex way as shown in

figure 14.1. Depending upon the temperature variation, atmosphere is divided into four regions. Temperature decreases from 17°C to −58°C regularly in the lowest layer extending upto 12 km. This layer of atmosphere is called troposphere. Above this layer lies the stratosphere that extends upto 50 km. In this layer temperature rises upto 2°C. Beyond the stratosphere lies the mesosphere, covering upto 85 km. In this region again temperature decreases down to −93°C. Beyond 85 km lies the thermosphere, in which temperature goes on increasing upwards.

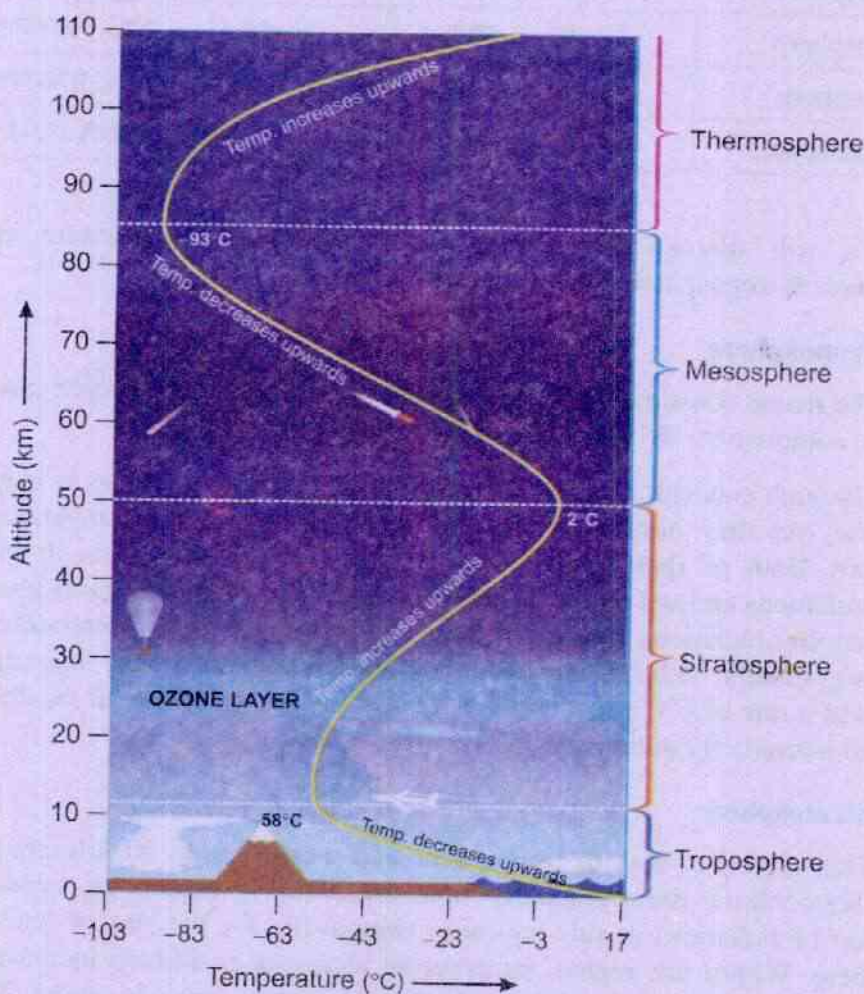



Fig. 14.1 Different spheres of atmosphere.

Characteristics of the four regions of the atmosphere are provided in the Table 14.2.

Table 14.2 Characteristics of Atmospheric Regions

Name of region	Height above the Earth's Surface	Temperature range and trend
Troposphere	0 — 12 km	17°C — –58°C (decreases)
Stratosphere	12 — 50 km	–58°C – 2°C (increases)
Mesosphere	50 — 85 km	2°C – –93°C (decreases)
Thermosphere	85 — 120 km	> –93°C (increases)

We will discuss the reasons of variations of temperature and other phenomenon in troposphere and stratosphere in detail.

14.2.1 Troposphere

The major constituents of troposphere are nitrogen and oxygen gases. These two gases comprise 99 % by volume of the Earth's atmosphere.

Although concentration of carbon dioxide and water vapours is negligible in atmosphere, yet they play a significant role in maintaining temperature of the atmosphere. Both of these gases allow visible light to pass through but absorb infrared radiations emitted by the Earth's surface. Therefore, these gases absorb much of the outgoing radiations and warm the atmosphere. As the concentration of gases decreases gradually with the increase of altitude, correspondingly temperature also decreases at a rate of 6°C per kilometre. This is the region where all weathers occur. Almost all aircrafts fly in this region.

14.2.2 Stratosphere

This region is next to troposphere and extends upto 50 kilometres. In this region, temperature rises gradually upto 2°C. The presence of ozone (due to absorption of radiation) in this region is responsible for the rise of temperature in stratosphere. Within this region, temperature increases as altitude increases, such as lower layer temperature is about –58°C and upper layer is about 2°C. Thus, stratosphere is layered in temperature as shown in figure 14.2. Since ozone in the upper layer absorbs high energy ultraviolet radiations from the Sun, it breaks down into monoatomic (O) and diatomic oxygen (O_2).

$$O_{3(g)} \longrightarrow O_{2(g)} + O_{(g)}$$

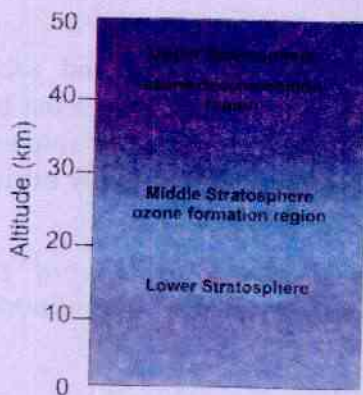
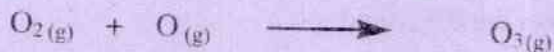



Fig. 14.2 Troposphere and stratosphere regions.

Interesting Information

Ozone is quite a well-known gas. Photocopiers and any other source of static electricity, can cause it to form from oxygen. You may have noticed a strange bitter smell near photocopiers; this is ozone. It is a poisonous gas and is formed on hot days in badly polluted cities.

The mid stratosphere has less UV light passing through it. Here O and O_2 recombine to form ozone which is an exothermic reaction. Ozone formation in this region results in formation of ozone layer. Thus, ozone layer exists in mid stratosphere.

$$O_{2(g)} + O_{(g)} \longrightarrow O_{3(g)}$$

The lower stratosphere receives very low UV radiations, thus monoatomic oxygen is not found here and ozone is not formed here.

Test yourself 14.1

- i- What do you mean by atmosphere?
- ii- What is difference between atmosphere and environment?
- iii- Name the major constituents of troposphere.
- iv- How the temperature of atmosphere is maintained?
- v- Where the ozone layer exists?
- vi- Why the temperature of upper stratosphere is higher?

14.3 POLLUTANTS

A pollutant is a waste material that pollutes air, water or soil. Three factors determine the severity of a pollutant, its chemical nature, concentration and persistence. These pollutants are being created and discharged to the environment by human activities. They make the environment (air, water or soil) harmful to life.

So the pollutants are those substances which cause pollution. While contaminants are those substances that make something impure.

The harmful substances present in air are called air pollutants. Even a beneficial substance beyond a specific concentration may be harmful. Air pollutants change the weather, badly affects the human health, damage the plants and destroy buildings.

14.3.1 Types of Pollutants

Major air pollutants are classified as primary pollutants and secondary pollutants. **Primary pollutants** are the waste or exhaust products driven out because of combustion of fossil fuels and organic matter. These are oxides of sulphur (SO_2 and SO_3); oxides of carbon (CO_2 and CO); oxides of nitrogen (specially nitric oxide NO); hydrocarbon (CH_4); ammonia and compounds of fluorine.

***Secondary pollutants** are produced by various reactions of primary pollutants.* These are sulphuric acid, carbonic acid, nitric acid, hydrofluoric acid, ozone and peroxy acetyl nitrate (PAN).

14.3.2 Sources of Air Pollutants

As you know 99% of atmosphere consists of N_2 and O_2. Although other gases are minor constituents, they can have major effects on our environment. Because atmosphere determines the environments in which we live. So, these minor constituents are safe upto a concentration limit. But in some areas this limit has been crossed considerably during the last 60 years because of human activities. Different sources of air pollutants are described as:

(i) Oxides of Carbon (CO_2 and CO)

Sources of oxides of carbon are as follows:

(a) Both of these gases are emitted due to volcanic eruption and decomposition of organic matter naturally.

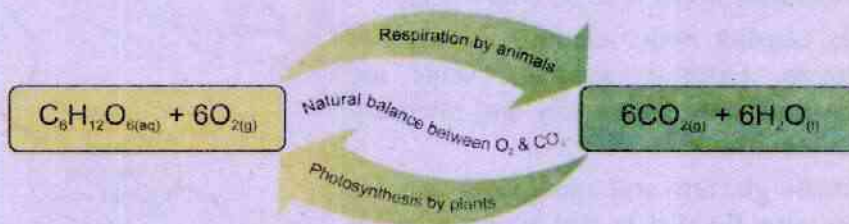
(b) However, the major source for the emission of these gases is combustion of fossil fuels (coal, petroleum and natural gas). Fossil fuels burnt in combustion engine of any type of automobile, kiln of any industry, or open air fires emit CO_2 and CO.

(c) Forest fires and burning of wood also emit CO_2 and CO. Especially, when supply of oxygen is limited, emission of CO dominates.

Greenhouse Effect and Global Warming

The CO_2 forms a layer around the Earth like an envelope. It allows the heat rays of the Sun to pass through it and reaches upto the Earth. These rays are reflected from the Earth surface and go back to upper atmosphere as shown in figure 14.3(a). Normal concentration of CO_2 layer retains enough heat to keep the atmosphere warm. So, normal concentration of CO_2 is necessary and beneficial for keeping the temperature warm. Otherwise, the Earth would have been uninhabitable. The Earth's average temperature would be about –20°C, rather than presently average temperature 15°C.

CO_2 is not an air pollutant. Rather, it is an essential gas for plants as O_2 is essential for animals. Plants consume CO_2 in photosynthesis process and produce

O_2. While animals use O_2 in respiration and give out CO_2. In this way, a natural balance exists between these essential gases as represented here. But this balance is being disturbed by emitting more and more CO_2 in air through different human activities.

Although $\mathbf{CO_2}$ is not a poisonous gas, yet its increasing concentration due to burning of fossil fuels in different human activities is alarming. Because CO_2 in the atmosphere acts like a glass wall of a green house. It allows UV radiations to pass through it but does not allow the IR radiations to pass through it. It traps some of the infrared radiations emitted by the Earth. Hence, increased concentration of CO_2 layer absorbs the infrared radiations emitted by the Earth's surface that prevents heat energy escaping from the atmosphere. It helps to stop surface from cooling down during night. As the concentration of CO_2 in air increases, less heat energy is lost from the surface of the Earth. Therefore, the average temperature of the surface gradually increases. This is called **greenhouse effect** as shown in figure 14.3(b). This effect is proportional to amount of CO_2 in air. Greater is amount of CO_2, more is trapping of heat or warming. Due to increased warming this phenomenon is also called global warming.

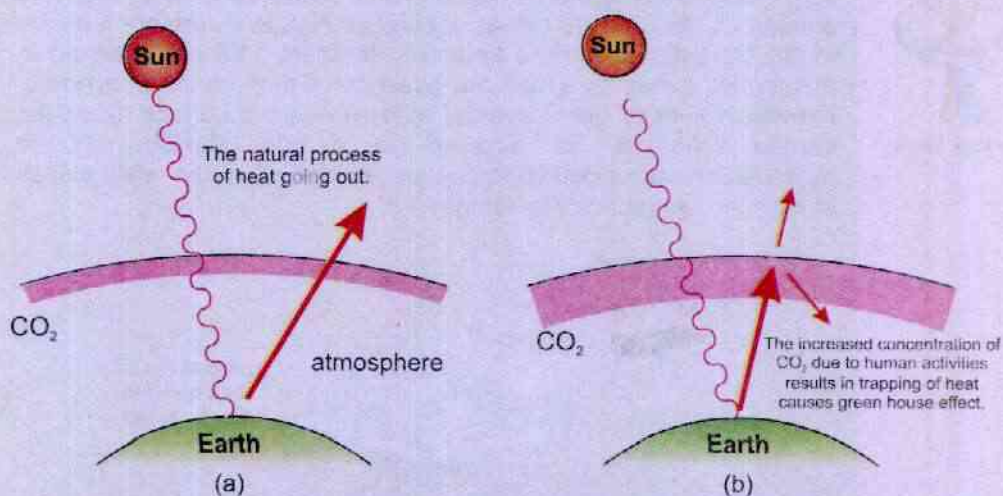



Fig. 14.3 Greenhouse effect.

Effects of global warming

(i) Accumulation of carbon dioxide in air is resulting in increasing atmospheric temperature about 0.05 °C every year.

(ii) It is causing major changes in weather patterns. Extreme weather events are occurring more commonly and intensely than previously.

(iii) It melts glaciers and snow caps that are increasing flood risks and intense tropical cyclones.

(iv) Sea-level is rising due to which low lying areas are liable to be submerged, turning previously populated areas no longer habitable.

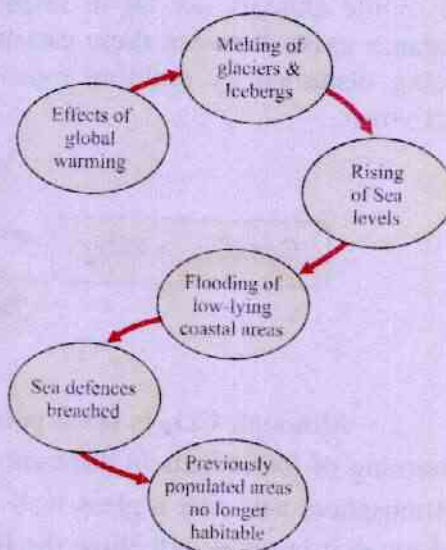



Fig. 14.4 Effect of global warming

Do you know

CO is an air pollutant. It is a health hazard being highly poisonous gas. Being colourless and odourless, its presence cannot be noticed easily and readily. When inhaled, it binds with the haemoglobin most strongly than that of oxygen. Thus, hindering the supply of oxygen in body. Exposure to higher concentration of CO causes headache and fatigue. If inhaled for a longer time it results in breathing difficulties and ultimately death. It is the reason burning is not allowed in closed places. It is advised to switch off coal or gas heaters, cooking range, etc., before going to sleep.

Do you know

Converters should be used in automobile exhaust so that they convert CO to CO_2 and oxides of nitrogen NO_x to N_2. before it enters in air. Catalytic converters as shown in figure 14.5 are attached to automobile exhausts. When hot gases pass through the converters, harmful pollutants are converted to harmless substances. Such as, carbon monoxide is oxidized to carbon dioxide, unburnt hydrocarbons are oxidized to carbon dioxide and water, while oxides of nitrogen are reduced to nitrogen.

Fig. 14.5 Catalytic converter used in automobile vehicles.

Interesting Information

- *CO_2 is the 'life gas' for plants as O_2 is for the human beings and animals.*
- *CO_2 absorbs infrared radiations emitted by the Earth. Although CO_2 is negligible as compared to N_2 and O_2, yet its heat retaining capacity is tremendous. Without CO_2, life on earth would have been impossible.*

(ii) Sulphur Compounds:

Naturally occurring sulphur containing compounds are emitted in the bacterial decay of organic matter, in volcanic gases and forest fires. But the concentration of sulphur containing compounds in the atmosphere because of natural sources is very small as compared to the concentration of those compounds emitted by fossil fuel combustion in automobiles and industrial units. About 80% of the total SO_2 is released by the combustion of coal and petroleum products as shown in figure 14.6.

Fossil fuels contain Sulphur → Fossil fuels are burned to produce energy → The Sulphur in the fuel forms oxides of sulphur. SO_2 & SO_3 → Oxides of sulphur escape into the air. They are air pollutants. → Oxides of sulphur dissolve in water and form Acid Rain. That falls on the earth

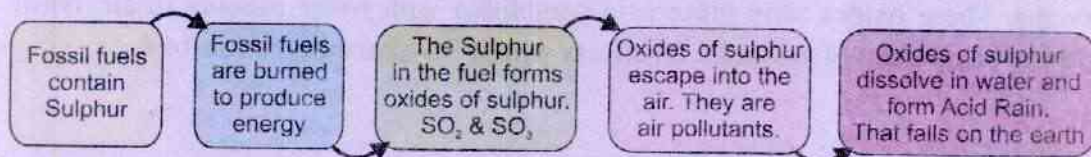



Fig. 14.6 Formation of SO_3 & SO_2 on combustion of fossil fuel and causing air pollution.

Effects of SO_2:

(i) SO_2 is a colourless gas having irritating smell. It causes suffocation, irritation and severe respiratory problems to asthmatic people.

(ii) SO_2 forms sulphuric acid which damages buildings and vegetations. Detail of it will be discussed in section 14.4 .

To control pollution because of SO_2, it is necessary to remove sulphur from fossil fuels before they are burnt.

Interesting Information

Acidic gases (pollutants) from nearby industrial units contribute to the wearing away of the famous marble building, the Taj Mahal in India.

(iii) Nitrogen Compounds (NO_x):

Naturally occurring oxides of nitrogen, mainly nitric oxide (NO), is produced by the electrical lightening in air.

Combustion of fossil fuels in internal combustion engines, in thermal power stations and factories where huge amount of coal is burnt, NO is formed by the direct combination of nitrogen and oxygen as shown in figure 14.7.

$$N_{2(g)} + O_{2(g)} \longrightarrow 2NO_{(g)}$$

However, it quickly reacts with air to form nitrogen dioxide. NO_2 is highly toxic gas.

$$2NO_{(g)} + O_{2(g)} \longrightarrow 2NO_{2(g)}$$

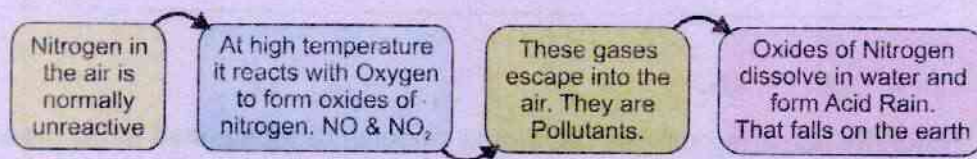
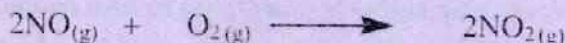



Fig. 14.7 Formation of NO & NO_2 on combustion of fossil fuel and causing air pollution.

Mixture of these gases represented as NO_x enter in the air through automobile exhaust and chimneys of thermal power station and factories. It irritates breathing passage. These oxides form nitric acid combining with water vapours in air. Nitric acid is a component of acid rain. Its effects will be discussed in section 14.4.

i. What do you mean by an air pollutant?

ii. Name three primary air pollutants.

iii. Identify as primary or secondary air pollutant.
SO_2, CH_4, HNO_3, NH_3, H_2SO_4, O_3.

iv. Why CO_2 is called a greenhouse gas?

v. Why the flood risks are increasing?

vi. Comment: burning in open air is preferred.

vii. How sulphur containing compounds are emitted naturally?

viii. How combustion of fossil fuels in internal combustion engine produces oxides of nitrogen?

Role of Government to control pollution:

Causing air pollution through auto exhaust is almost the most common air polluting act which an average citizen commits daily for hours without considering its consequences. One is poisoning the air, creating a big problem that has local, regional and global effects.

Government should do short term as well as long term planning to preserve the natural world. Because without a healthy natural environment, there will be no healthy human, plant, or animal.

(i) First of all, quality of fuel must be improved by adding anti-knocking agents in fuels. At the same time, automobiles combustion engines must be efficient so that they should burn the fuel completely. No unburned hydrocarbon molecules (fuel) should come out of the exhaust. So government must guide the people to use converters in auto exhausts.

(ii) Fossil fuels produce a number of air pollutants because of impurities and complex molecule nature of hydrocarbons. Government should promote the use of alternative fuels such as methanol, ethanol and bio-diesel. These fuels are less polluting than hydrocarbons fuel, as their molecules are simple, and burn completely in the engine. Their burning produces less carbon monoxide, soot and other pollutants.

(iii) The government must plan to avoid using carbon dioxide producing fuels as it is a greenhouse gas. It should go to battery-powered electric vehicles.

(iv) Government should provide efficient transport in the big cities, so that people should avoid using their own vehicles.

14.4 ACID RAIN AND ITS EFFECTS

As you have studied, burning of fossil fuels produces oxides of sulphur and nitrogen in air. Rain water converts SO_2 into H_2SO_4 and NO_x to HNO_2 and HNO_3. Normal rain water is weakly acidic because it consists of dissolved CO_2 of the air. Its pH is about 5.6 to 6. But rain water on dissolving air pollutants (acids) becomes more acidic and its pH reduces to 4. Thus, acid rain is formed on dissolving acidic air pollutants such as sulphur dioxide and nitrogen dioxide by rain water.

Figure 14.8 shows how oxides of sulphur and nitrogen are converted into acids. These acids dissolve in rain water and damage soil, animals, plants and aquatic life.

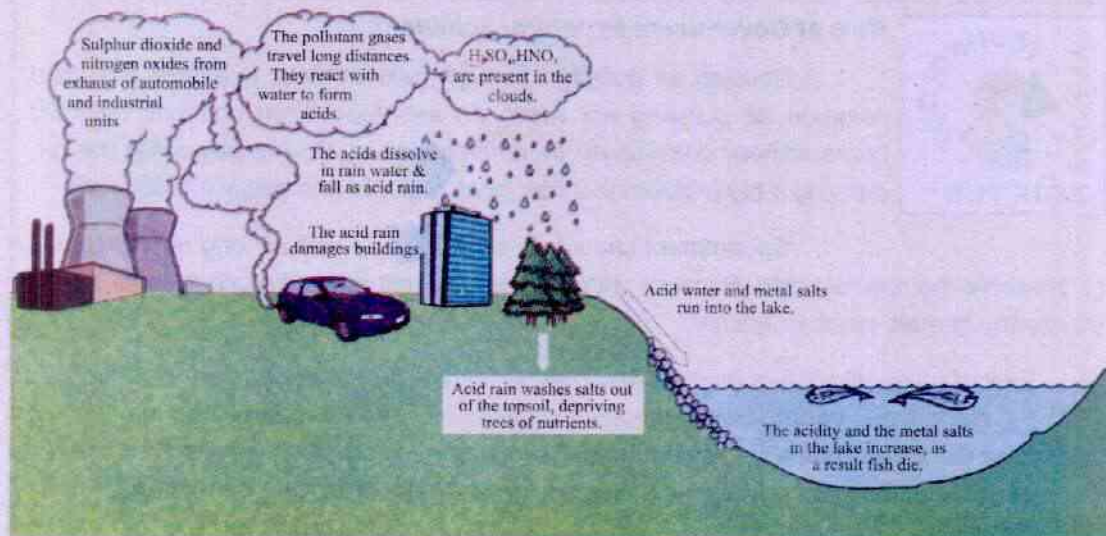



Fig. 14.8 Acid rain formation and its effects

Effects of acid rain

(i) Acid rain on soil and rocks leaches heavy metals (Al, Hg, Pb, Cr, etc) with it and discharges these metals into rivers and lakes. This water is used by human beings for drinking purpose. These metals accumulate in human body to a toxic level. On the other hand, aquatic life present in lakes also suffers because of high concentration of these metals. Especially high concentration of aluminium ions clogs the fish gills. It causes suffocation and ultimately death of fish.

(ii) Acid rain attacks the calcium carbonate present in the marble and limestone of buildings and monuments. Thus, these buildings are getting dull and eroded day by day.

(iii) Acid rain increases the acidity of the soil. Many crops and plants cannot grow properly in such soil. It also increases the toxic metals in the soil that poisons the vegetation. Even old trees are being affected due to acidity of soil. Their growth is retarded. They get dry and die.

(iv) Acid rain directly damages the leaves of trees and plants, thus limiting their growth. Depending upon the severity of the damage, plants growth can be hampered. Plants capability to resist cold or diseases reduces and ultimately die die as shown in figure 14.9.

Test yourself 14.3

i. *How is acid rain produced?*
ii. *Why acid rain damages buildings?*
iii. *How is aquatic life affected by acid rain?*
iv. *Why are plants dying day by day? Comment.*

Fig 14.9 Effect of acid rain on plants.

14.5 OZONE DEPLETION AND ITS EFFECTS

Ozone is an allotropic form of oxygen consisting of three oxygen atoms. It is formed in atmosphere by the association of an oxygen atom with an oxygen molecule in the mid of stratosphere.

$$O_{(g)} + O_{2(g)} \longrightarrow O_{3(g)}$$

Ozone is present throughout the atmosphere. *But its maximum concentration called **ozone layer** lies in stratosphere region about 25 to 30 km away from the Earth's surface.* This layer surrounds the globe and protects Earth like a shield from harmful ultraviolet radiations of sunlight as shown in figure 14.10. Otherwise, ultraviolet radiations would cause skin cancer. Thus ozone layer in stratosphere is beneficial for life on the Earth.

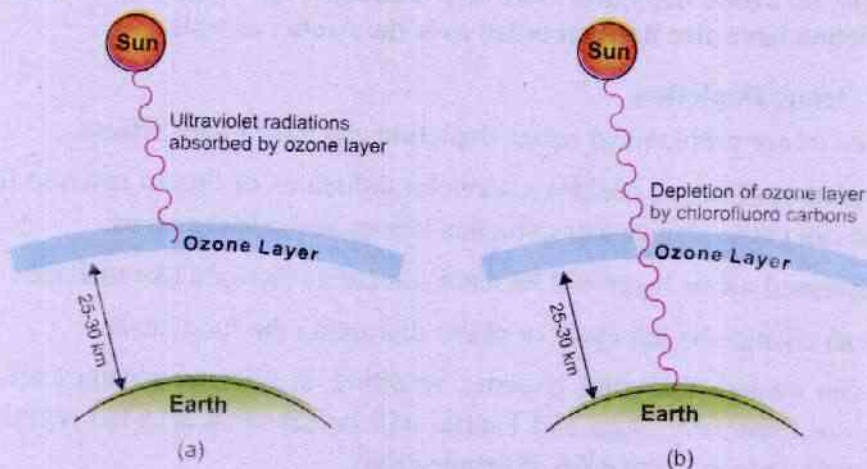



Fig. 14.10 (a) Ozone layer (b) Depletion of ozone layer.

Under normal conditions ozone concentration in stratosphere remains nearly constant through a series of complex atmospheric reactions. Two reactions that maintain a balance in ozone concentrations are as follows:

$$O_{2(g)} + O_{(g)} \longrightarrow O_{3(g)} \quad \text{(formation)}$$

$$O_{3(g)} + O_{(g)} \longrightarrow 2O_{2(g)} \quad \text{(decomposition)}$$

But this ozone layer is being depleted through various chemical reactions, such as:

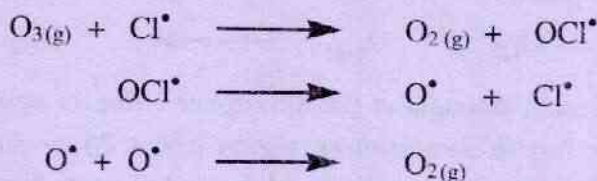
However, chlorofluorocarbons (CFCs) (used as refrigerants in air conditioners and refrigerators) are major cause of depletion of ozone layer. These compounds leak in one way or other escape and diffuse to stratosphere. Ultraviolet radiations break the C-Cl bond in $CFCl_3$ and generates chlorine free radicals as

$$CFCl_3 \xrightarrow{UV} CFCl_2 + Cl^{\bullet}$$

These free radicals are very reactive. They react with ozone to form oxygen as

$$O_{3(g)} + Cl^{\bullet} \longrightarrow O_{2(g)} + OCl^{\bullet}$$

$$OCl^{\bullet} \longrightarrow O^{\bullet} + Cl^{\bullet}$$

$$O^{\bullet} + O^{\bullet} \longrightarrow O_{2(g)}$$

A single chlorine free radical released by the decomposition of CFCs is capable of destroying upto many lacs of ozone molecules. *The region in which ozone layer depletes is called **ozone hole.***

Signs of ozone depletion were first noticed over Antarctica in 1980s. Since 1990s depletion have also been recorded over the Arctic, as well.

Effects of Ozone Depletion

Even minor problems of ozone depletion can have major effects.

(i) Depletion of ozone enables ultraviolet radiations of Sun to reach to the Earth, that can cause skin cancer to human beings and other animals.

(ii) Decreased ozone layer will increase infectious diseases like malaria.

(iii) It can change the life cycle of plants disrupting the food chain.

(iv) It can change the wind patterns, resulting in climatic changes all over the world. Especially, Asia and Pacific will be the most affected regions, facing climate-induced migration of people crisis.

i. Justify, ozone is beneficial for human kind.
ii. Why ozone is depleting in atmosphere?
iii. What do you mean by ozone hole?
iv. Where the ozone layer is found?

Incineration of waste material causes air pollution

Incineration is a waste treatment process that involves the burning of solid waste at high temperatures between 650°C to 1100°C in incinerators. Incinerators reduce the solid mass of the original waste by 80-85% and convert the waste materials into ash, flue gas and heat. Although, the volume of solid waste is reduced effectively by incineration, it produces highly poisonous gases and toxic ash. The flue gas includes, dioxins, furans, sulphur dioxide, carbon dioxide, carbon monoxide, hydrochloric acid and a large amount of particulate matter.

Key Points

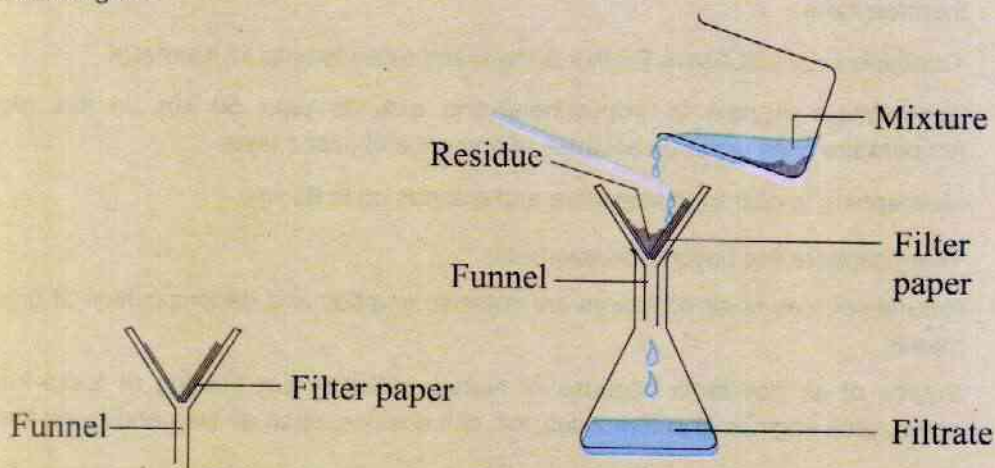
- Atmosphere is the envelope of different gases around the Earth.
- Atmosphere is divided into four regions; troposphere, stratosphere, mesosphere and thermosphere.
- Troposphere is just above Earth's surface and extends upto 12 kilometre.
- Stratosphere is next to troposphere and extends upto 50 km. In this region, temperature rises upwards because of presence of ozone layer.
- Mesosphere is next to stratosphere and extends up to 85 km.
- Thermosphere lies beyond mesosphere.
- Natural sources of air pollutants are volcanic eruption and decomposition of organic matter.
- Source of air pollutants because of human activities are burning of fossil fuel in combustion engines of automobiles, kiln of industries, open air fires and forest fires.
- CO_2 forms a layer around Earth, that absorbs the infrared radiations emitted by Earth surface. Thus heating up atmosphere, called greenhouse effect.
- CO is highly poisonous gas so it is health hazard.
- SO_2 is also health hazard and forms sulphuric acid by combining with water vapours in air. It is also a component of acid rain.

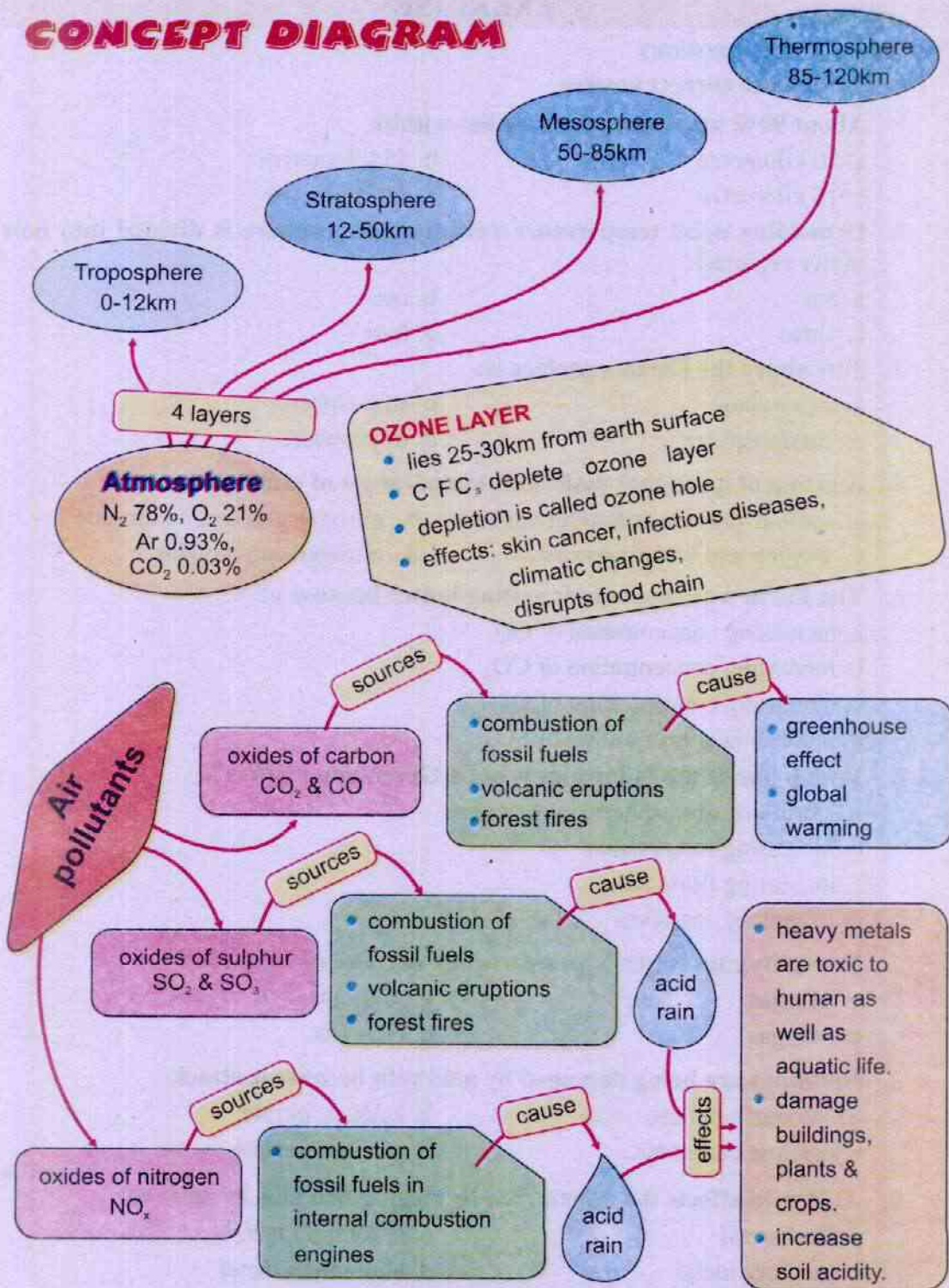
- Acid rain consists of H_2SO_4 and HNO_3 that reduces the pH of rain water to 4.
- Ozone layer lies in stratosphere about 25 to 30 km away from Earth's surface.
- Ozone layer protects Earth like a shield from harmful ultraviolet radiations of sunlight.
- Chlorofluorocarbons destroy ozone molecules, depleting the ozone called ozone hole.
- Depletion of ozone enables ultraviolet radiations of the Sun to reach the Earth; causing infectious diseases; changing the life cycle of plants, wind patterns.

SKILLS

Filtration of suspended impurities

Filtration is separation of insoluble solid particles (sand, clay, dust or precipitates) from a liquid. It is carried out by filtering a mixture. A filter paper is first folded half way, then another fold is made, so that a filter paper gets four folds. This folded filter paper is placed in a filter funnel in such a way that on one side are three layers and on the other side is one layer as shown in figure.

The mixture (sand in water or chalk in water) is poured into the filter paper as shown in figure.

Filtrate passes through the filter paper and is collected in a conical flask. The solid particles (residue) deposit on the filter paper. It is then dried.

CONCEPT DIAGRAM

EXERCISE

Multiple Choice Questions

Put a (✓)on the correct answer

1. **About 99% atmosphere's mass lies within:**
   a. 30 kilometre b. 35 kilometre
   c. 15 kilometre d. 11 kilometre
2. **Depending upon temperature variation, atmosphere is divided into how many regions?**
   a. one b. two
   c. three d. four
3. **Just above the Earth's surface is:**
   a. mesosphere b. stratosphere
   c. thermosphere d. troposphere
4. **A group of gases that maintains temperature of atmosphere is:**
   a. carbon dioxide and water vapours b. nitrogen and carbon dioxide
   c. oxygen and water vapours d. nitrogen and oxygen
5. **The Earth's atmosphere is getting hotter because of**
   a. increasing concentration of CO
   b. increasing concentration of CO_2
   c. increasing concentration of O_3
   d. increasing concentration of SO_2
6. **Which one of the followings is not a Greenhouse Effect?**
   a. increasing atmospheric temperature
   b. increasing food chains
   c. increasing flood risks
   d. increasing sea-level
7. **Normally rain water is weakly acidic because of**
   a. SO_3 gas b. CO_2 gas
   c. SO_2 gas d. NO_2 gas
8. **Buildings are being damaged by acid rain because it attacks:**
   a. calcium sulphate b. calcium nitrate
   c. calcium carbonate d. calcium oxalate
9. **Acid rain affects the aquatic life by cloging fish gills because of:**
   a. lead metal b. chromium metal
   c. mercury metal d. aluminium metal

10. Ozone is beneficial for us as it:

a. absorbs infrared radiations

b. absorbs ultraviolet radiations

c. absorbs chlorofluorocarbons

d. absorbs air pollutants

11. Which one of the following is not an air pollutant?

a. nitrogen b. carbon monoxide

c. nitrogen dioxide d. ozone

12. Iron and steel structures are damaged by

a. carbon monoxide b. sulphur dioxide

c. methane d. carbon dioxide

13. Infrared radiations emitted by the Earth are absorbed by:

a. CO_2 and H_2O b. N_2 and O_2

c. CO_2 and N_2 d. O_2 and CO_2

14. Global warming causes rising of the sea level. The cause of global warming is:

a. CO_2 gas b. SO_2 gas

c. NO_x gases d. O_3 gas

15. Which gas protects the Earth's surface from ultraviolet radiations?

a. CO_2 b. CO

c. N_2 d. O_3

16. Effects of ozone depletion are following except the one;

a. increases infectious diseases b. increases crops production

c. can cause skin cancer d. can cause climatic changes

17. Which one of these pollutants are not found in car exhaust fumes?

a. CO b. O_3

c. NO_2 d. SO_2

18. The process by which atmospheric nitrogen is turned into nitrates in the soil is called:

a. nitration b. fixing

c. oxidation d. reduction

19. Global warming is because of:

a. absorption of infrared radiations emitted by the Earth's surface

b. absorption of infrared radiations coming from the Sun

c. absorption of ultraviolet radiation coming from the Sun

d. emission of ultraviolet radiation from the Earth's surface

20. Carbon monoxide is harmful to us because:

a. it paralyses the lungs

b. it damages lungs tissues

c. it reduces oxygen carrying ability of haemoglobin

d. it makes the blood coagulate

Short Answer Questions

1. Explain the phenomenon of decreasing temperature in troposphere.
2. Differentiate between primary and secondary air pollutants.
3. State the major sources of CO and CO_2 emission.
4. CO_2 is responsible for heating up atmosphere, how?
5. CO is an hidden enemy, explain its action.
6. What threats are to human health due to SO_2 gas as air pollutant?
7. Which air pollutant is produced on anaerobic decomposition of organic matter?
8. How acid rain increases the acidity of soil?
9. Point out two serious effects of ozone depletion.
10. How ozone layer forms in stratosphere?
11. Why the 75% of the atmospheric mass lies within the troposphere?
12. How ozone layer is being depleted by chlorofluoro carbons?

Long Answer Questions

1. Write down the significance of atmospheric gases.
2. Give the characteristics of troposphere. Why temperature decreases upwards in this sphere?
3. What are the characteristics of stratosphere? Why temperature increases upwards in this sphere?
4. CO_2 is necessary for plants but why its increasing concentration is alarming for us?
5. Why is CO considered a health hazard?
6. Define acid rain. How it forms and what are its effects?
7. Compounds of sulphur are air pollutants. Describe the sources of these compounds along with their effects.
8. Where does ozone layer lie in atmosphere? How it is depleting and how we can prevent its depletion?
9. Oxides of nitrogen cause air pollution. Describe the sources of these compounds.

Chapter 15

Environmental Chemistry II

WATER

Major Topics

15.1 Properties of Water
15.2 Water as Solvent
15.3 Soft and Hard Water
15.4 Types of Hardness
15.5 Methods of Removing Hardness
15.6 Disadvantages of Water Hardness
15.7 Water Pollution
15.8 Waterborne Diseases

Time allocation

Teaching periods	10
Assessment periods	02
Weightage	8%

Students Learning Outcomes

Students will be able to:

- describe the occurrence of water and its importance in the environment including industry. (Analyzing);
- review our dependence on water and its importance of maintaining its quality. (Analyzing);
- describe the composition and properties of water. (Understanding);
- differentiate among soft, temporary and permanent hard water. (Analyzing);
- describe methods for eliminating temporary and permanent hardness of water.(Applying);
- identify water pollutants.(Analyzing);
- describe industrial wastes and household wastes as water pollutants. (Understanding);
- describe the effects of these pollutants on life. (Understanding) and
- describe the various types of waterborne diseases. (Understanding)

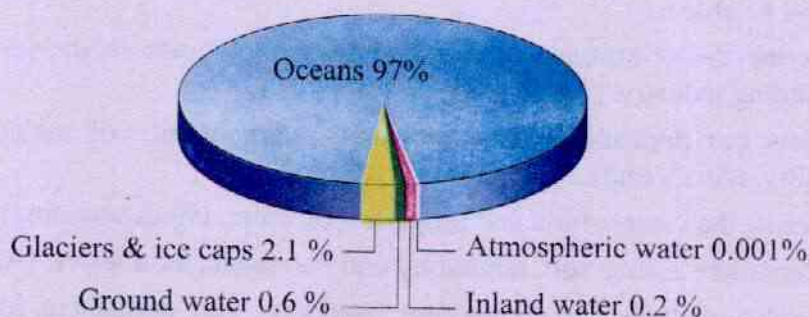
Introduction

Throughout history, importance and significance of water has been recognized by mankind. Its importance is because of two reasons. Firstly, it is an essential and major component of each and every living cell. For example, human body consists of about 70% water. Secondly, it provides an environment for animals and plants that live in water. So, all living organisms owe their life because of water.

We use water in daily life for drinking, cooking and washing purposes. Quality of drinking water has remained a major factor in determining human health and welfare since ages. Since World War II, there has been a rapid production and use of synthetic chemicals. Many of these chemicals (fertilizers and pesticides run off from agriculture lands and industrial discharge from industrial units) have polluted water supplies. Besides this, there is also a threat to ground water from waste chemical dumps and landfills.

Currently, waterborne toxic chemicals pose the greatest threat to the supplies of water especially in urban areas. Use of this water is causing water borne diseases. So use of polluted water is a concern of every citizen. Therefore, understanding the sources and effects of water pollution is essential for controlling this alarming threat.

Occurrence of Water

The oceans contain about 97% of world water. The rest of the water is in the form of glaciers, ice caps, ground water and inland water (river, lakes, streams). It is also present in atmosphere in the form of water vapours.

Distribution of water

Sea water is unfit for drinking and agricultural purposes due to high percentage of dissolved salts. Only 0.2% of the total water on the Earth is potable, i.e. fit for drinking purposes.

15.1 PROPERTIES OF WATER

Water is composed of two elements: oxygen and hydrogen. One atom of oxygen combines with two atoms of hydrogen to form one molecule of water. Pure water is a clear, colourless, odourless and tasteless liquid with following properties:

(i) It is neutral to litmus.

(ii) Its freezing point is 0°C and boiling point is 100 °C at sea level.

(iii) Its maximum density is 1 gcm^{-3} at 4°C.

(iv) It is excellent solvent for ionic as well as molecular compounds.

(v) It has unusually high that of **heat capacity** about 4.2 $Jg^{-1}K^{-1}$, which is about six times greater than that of rocks. This specific property of water is responsible for keeping the Earth's temperature within limits. Otherwise, day time temperature would have been too high to bear and night time temperature would have been too low to freeze everything.

(vi) It has high surface tension. This unique property of water is responsible for its high capillary action. ***Capillary action*** *is the process by which water rises up from the roots of plants to leaves.* This process is vital for the survival of the land plants.

15.2 WATER AS SOLVENT

Water is the universal solvent because it can dissolve almost all the minerals.

Its ability to dissolve substances is because of two unique properties of water:

(i) polarity of water molecule;

(ii) exceptional hydrogen bonding ability.

(i) Polar nature of water

Water molecule has polar structure, i.e. one end of the molecule is partially positive while the other end is partially negative because of electronegativity difference between oxygen and hydrogen atoms.

All other polar substances are soluble in water, because the positive end of the substance is attracted by the negative end ($O^{\delta-}$) of the water and negative end of the substance is attracted by the positive end ($H^{\delta+}$) of the water. The electrostatic attractions among the ions are overcome by the ion-dipole forces of attraction between ion and water molecules. In this way, positive and negative ions of the compounds are pulled apart as shown in figure 15.1. Ultimately, these oppositely charged ions are surrounded by water molecules, thus separated and kept in solution. For example, most of the salts like NaCl, KCl, Na_2SO_4, etc. are soluble in water.

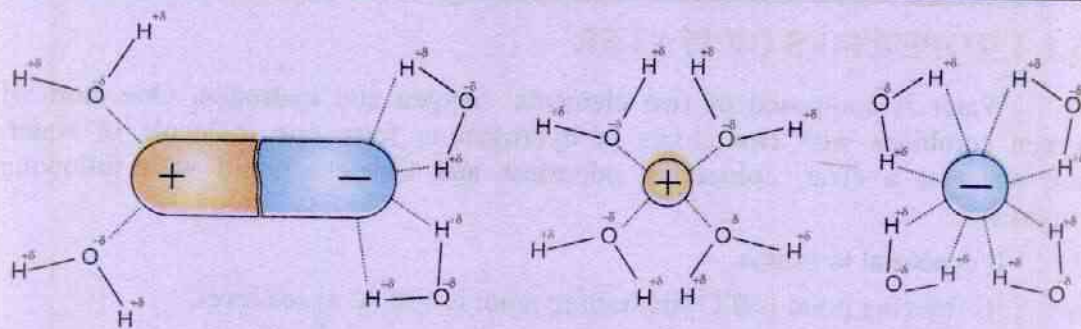



Fig. 15.1 Dissolving process of a polar substance in water.

On the other hand, many covalent substances like benzene, ether, octane, etc., which do not have polar ends or bonds are not attracted by water molecules. Therefore, non-polar compounds do not dissolve in water.

(ii) Extensive hydrogen bonding ability

Water molecule is composed of oxygen and hydrogen atoms.

Because of two O−H bonds and two lone pairs, one H_2O molecule can form hydrogen bonding with four other H_2O molecules, which are arranged tetrahedrally around the H_2O molecule as shown in Figure 15.2. This unique behaviour of water enables it to dissolve many polar non-ionic compounds having hydroxyl group (-OH), like alcohols, organic acids, glucose, sugar, etc. by forming hydrogen bonds with them.

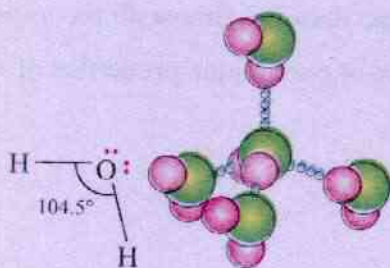



Fig. 15.2 Hydrogen bonding of water molecule.

If you add a lump of caesium to water in a glass trough, the reaction is so vigorous that the trough will shatter into small pieces.

Test yourself 15.1

i. What is capillary action?

ii. Point out two properties of water that make it an excellent solvent.

iii. Why the water molecule is polar?

iv. Explain why nonionic polar compounds are soluble in water?

15.3 SOFT AND HARD WATER

Soft water

Soft water is that which produces good lather with soap.

Hard water

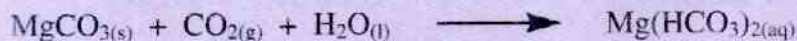
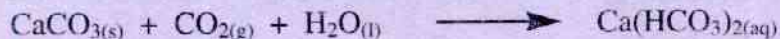
Hard water is that which does not produce lather with soap.

Causes of hardness in water.

The rain water while coming down absorbs carbon dioxide from the atmosphere. The water mixed with carbon dioxide, when passes through the beds of the soil, converts insoluble carbonates of calcium and magnesium into soluble bicarbonates. It may also dissolve chlorides and sulphates of calcium and magnesium.

These salts make the water hard.

$$CaCO_{3(s)} + CO_{2(g)} + H_2O_{(l)} \longrightarrow Ca(HCO_3)_{2(aq)}$$

$$MgCO_{3(s)} + CO_{2(g)} + H_2O_{(l)} \longrightarrow Mg(HCO_3)_{2(aq)}$$

Thus, rain water dissolves many salts of divalent cations like Mg^{2+}, Ca^{2+}, and anions like Cl^-, SO_4^{2-}, HCO_3^- and CO_3^{2-} for example, gypsum ($CaSO_4.2H_2O$) and limestone ($CaCO_3$). These salts make the water hard.

Gypsum is sparingly soluble in water, while limestone is insoluble in water. However, in the presence of carbon dioxide small quantity of limestone is soluble in water according to the above chemical reaction.

15.3.1 Types of Hardness of Water

Hardness is of two types:

(i) *Temporary hardness is because of presence of bicarbonates of calcium and magnesium.*

(ii) *Permanent hardness is because of presence of sulphates and chlorides of calcium and magnesium.*

15.3.2 Methods of Removing Hardness

The removal of Mg^{2+} and Ca^{2+} ions which are responsible for the hardness is called ***water softening.***

(i) Removal of temporary hardness

(a) By boiling

Temporary hardness of water is easily removed by boiling water. On boiling, calcium bicarbonate $Ca(HCO_3)_2$ decomposes to produce insoluble calcium carbonate, which precipitates out of the solution.

$$Ca(HCO_3)_{2(aq)} \xrightarrow{\Delta} CaCO_{3(s)} + H_2O + CO_{2(g)}$$

(b) Clark's method

A chemical method to remove temporary hardness is by the addition of slaked lime $Ca(OH)_2$. A calculated amount of lime water is added to temporary hard water.

$$Mg(HCO_3)_{2(aq)} + Ca(OH)_{2(aq)} \longrightarrow Mg\,CO_{3(s)} + Ca\,CO_{3(s)} + 2H_2O_{(l)}$$

$$Ca(HCO_3)_{2(aq)} + Ca(OH)_{2(aq)} \longrightarrow 2CaCO_{3(s)} + 2H_2O_{(l)}$$

Thus, once the magnesium and calcium ions precipitate out water becomes soft.

(ii) Removal of permanent hardness

Permanent hardness can only be removed by using chemicals. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) are removed as insoluble salts by adding washing soda (Na_2CO_3) or sodium zeolite.

(a) *By using **washing soda**:* The addition of washing soda removes the calcium and magnesium ions as the insoluble calcium and magnesium carbonates, respectively.

$$Na_2CO_{3(aq)} + CaSO_{4(aq)} \longrightarrow CaCO_{3(s)} + Na_2SO_{4(aq)}$$

$$Na_2CO_{3(aq)} + MgSO_{4(aq)} \longrightarrow MgCO_{3(s)} + Na_2SO_{4(aq)}$$

(b) *Using **Sodium Zeolite** (an ion Exchanger)* Sodium zeolite is a naturally occurring resin of sodium aluminium silicate $NaAl(SiO_3)_2$, which can also be prepared artificially. It is used for softening of water at domestic as well as on industrial scale. When water is passed through resin, sodium ions of the resin are exchanged with the unwanted calcium and magnesium ions of the hard water as shown in figure 15.3.

$$Na_2\ zeolite + CaSO_{4(aq)} \longrightarrow Ca\ zeolite + Na_2SO_{4(aq)}$$

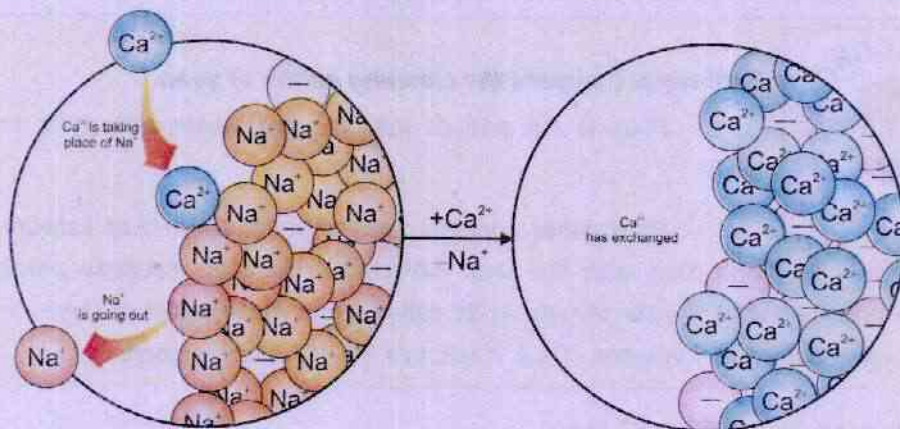



Fig. 15.3 Ion exchange for removal of hard water ions

When resin is fully used up it can be regenerated by flushing it with concentrated solution of NaCl. The reverse process takes place because of high concentration of sodium ions.

$$\text{Ca zeolite} + 2NaCl \longrightarrow Na_2\text{ zeolite} + CaCl_2$$

15.2.3 Disadvantages of Hard Water:

(i) Hard water consumes large amount of soap in washing purposes.

(ii) Drinking hard water causes stomach disorders.

(iii) Hard water is unfit for use in steam engines, boilers and turbines because insoluble calcium and magnesium salts deposit inside. They are called scales. They are bad conductors of heat and hence more fuel is used. Insoluble calcium and magnesium sulphates not only reduce the efficiency of the engine but also cause the boiler to burst.

Test yourself 15.2

i. *Which salts are responsible for hardness of water?*

ii. *Explain the chemistry of removing the temporary hardness by boiling water.*

iii. *What is the principle of removing permanent hardness of water?*

iv. *How addition of Na_2CO_3 removes permanent hardness of water?*

v. *How sodium zeolite softens water?*

vi. *What do you mean by boiler scales? How are they removed?*

Hard water hampers the cleaning action of soap.

Soap is the sodium salt of a long chain carboxylic acid (fatty acid).

Hard water contains salts of magnesium and calcium. These ions react with the soap molecule to form an insoluble precipitate of calcium and magnesium salts of fatty acids called scum. As a result, a large amount of soap is wasted in scum formation. Thus, it reduces the efficiency of soap.

15.4 WATER POLLUTION

Water pollution is a contamination of water bodies (e.g. lakes, rivers, oceans and ground water). Water pollution occurs when pollutants are discharged directly or indirectly into water bodies without adequate treatment to remove harmful compounds.

15.4.1 Industrial Effluents

Industrial units are installed to produce the desired substances (chemicals, cloth, leather goods, paper, plastic items, petrochemicals and rubber items) on commercial scale to meet the needs of the society. But unfortunately all the industrial units discharge their wastes *(chemicals and solid materials)* either to open ground or to water channels. *This is called* ***industrial effluent****. The industrial effluent may be highly toxic organic chemicals, inorganic salts, heavy metals, mineral acids, oil and greases, etc.* On the other hand, water used as cleaning agent in industries is directly discharged out. This water contains all kinds of toxic chemicals and detergents.

When these effluents and used water enter lakes, streams, rivers or oceans, they either get dissolved or float suspended in water. Even they get deposited on the bed. This results in the pollution of water, i.e.

(i) They deteriorate the quality of water.

(ii) They reduce the quantity of dissolved oxygen which ultimately affects aquatic life and ecosystem.

(iii) They can also seep down and affect the ground water deposits. They contaminate the water deposits. When this water is used by human beings, it causes serious diseases like cancer and gastro. This polluted water damages soil, crops, plants and animals.

(iv) Heavy metals like cadmium, lead and mercury are toxic and health hazards for human beings. Acute cadmium poisoning causes high blood pressure, kidney damage and destruction of red blood cells. Acute lead poisoning causes dysfunction of kidney, liver, brain, central nervous

system and reproductive system. Mercury poisoning causes neurological damage.

15.4.2 Domestic Effluents

Use of **detergents** is increasing day by day for cleaning purposes in houses and industries. It is because, detergents have strong cleaning action than that of soap even in hard water. They can work even in acidic solutions. But they have a major disadvantage over the soaps, *as some of the detergents are non-biodegradable (cannot be decomposed by microorganisms like bacteria).* When household water containing these detergents is discharged in streams, ponds, lakes and rivers, it causes water pollution.

The detergent remains in the water for a long time and makes the water unfit for aquatic life. The phosphate salts present in detergents cause rapid growth of algae in water bodies, which floats over the surface of water. These plants ultimately die and decay. Decaying plants being biodegradable consume oxygen gas present in water. Thus, depletion of oxygen gas results in death of aquatic life.

Domestic sewage contains a wide variety of dissolved and suspended impurities. They include food and vegetable waste, garbage, cans, bottles, chemical soaps, washing powder, etc. It also contains disease causing microbes. All these substances add to water pollution.

15.4.3 Agricultural Effluents

Water pollution due to agricultural waste is because of use of fertilizers and pesticides. Fertilizers are used to make up the deficiency of nitrogen, phosphorus, etc. of the soil because of intensive cultivation of crops in the recent years.

On the other hand, pesticides are used either directly to kill or control the growth of pests. Pests may be weeds, herbs, insects, fungi, viruses, etc. They all damage crops and transmit diseases both to human beings and animals.

Agricultural effluents have dual effects:

(i) Intensive cultivation of crops causes these chemicals from fertilizers and pesticides to seep into the ground water commonly called leaching process. The high nitrate contents in ground water is mainly because of irrigation run-off from agricultural fields.

(ii) Run-off from the agricultural land (where fertilizers and pesticides have been used) enters into ponds, streams or rivers. This water contains nitrate (NO_3^-) and phosphate (PO_4^{3-}) salts. These substances results in a rapid growth of algae, floating over the surface of water. They prevent the sunlight and air (oxygen) to reach upto aquatic life. When algae dies, bacteria consume oxygen of the water

for decomposition of algae. As a result oxygen depletes in the water. Aquatic animals feel suffocation and ultimately die due to insufficient supply of oxygen.

Effects of Water Pollution

Water pollution has the following effects:

(i) It is hazardous to human health. Drinking polluted water can cause cholera, typhoid and diarrhea.

(ii) The use of polluted water is not only devastating for people but also for animals and birds.

Interesting Information

In some parts of the world, the water supply contains small amounts of fluorine compounds. It was found that, in these areas, people did not suffer much from tooth decay. This is because compounds of fluorine protect teeth from decay. This is why many tooth-pastes contain fluorine compounds.

(iii) It causes rapid growth of algae. Death and decomposition of algae causes deficiency of oxygen in water that affects organism living in water.

(iv) It is damaging aquatic life, thus breaking a link in food chain.

(v) It reduces the aesthetic quality of lakes and rivers.

(vi) It is unfit for cleaning or washing purposes.

Test yourself 15.3

i. *What is an industrial waste?*
ii. *How water used as a cleaning agent in industries causes pollution?*
iii. *Why use of detergents is increasing day by day?*
iv. *How decaying plants consume oxygen?*
v. *What is function of fertilizers?*
vi. *How pesticides cause water pollution?*

15.5 WATERBORNE INFECTIOUS DISEASES

Diseases that spread because of drinking polluted water or eating food prepared with polluted water are called ***waterborne infectious diseases***. Water pollution may be due to toxins or microorganisms. Toxins are arsenic, mercury, arsenic, lead and many organic chemicals. Microorganisms are viruses, bacteria, protozoa and worms.

Lack of proper sanitation facilities is the main cause of rapidly spreading water borne diseases. A few common diseases are mentioned here:

(i) Diarrheal diseases

Intestinal diseases, such as cholera, that may cause dangerous dehydration. Diarrhea may be caused by viruses, bacteria or parasites.

(ii) Dysentery

Dysentery is an intestinal disease which is typically caused by certain bacteria or parasites. It is characterized by severe diarrhea that may be accompanied by blood or mucous.

(iii) Cholera

Cholera is an acute infection caused by the bacteria *Vibrios cholerae*, which may be found in water contaminated by human feaces. Cholera causes severe diarrhea and can be fatal.

(iv) Cryptosporidium

Waterborne micro organism (protozoa) that causes gastrointestinal illness (cryptosporidiosis) including diarrhea and vomiting. These tiny pathogens are found in surface water sources like reservoirs, lakes and rivers.

(v) Fluorosis

Fluorosis is a disease caused by the consumption of excess fluoride. Fluorosis can cause bones and teeth damage.

(vi) Hepatitis

It is liver inflammation commonly caused by one of five viruses called hepatitis A, B, C, D, and E. Hepatitis A and E can be transmitted by contaminated water.

(vii) Hookworm

Hookworm is a parasitic worm that infects the small intestine. Severe cases can result in anemia and stunted growth in children. Hookworm larvae enter the body through the skin, often via the feet. Spread by poor sanitary conditions, hookworms infect about one billion people worldwide per annum.

(viii) Jaundice

Jaundice is caused by an excess of bile pigments in the blood. Liver ceases to function and eyes turn yellow. Patient feels weakness and fatigue.

(ix) Typhoid

A dangerous bacterial disease often spread by contaminated water or by food prepared with contaminated water.

Prevention of waterborne diseases

Waterborne diseases can be prevented by taking the following measures:

(i) *Provision of safe water:* Drinking water must be properly treated and purified.

(ii) *Disposal of sewage:* There must be adequate sanitary disposal of sewage. Any type of waste must not be thrown or discharged directly in water supplies or reservoirs.

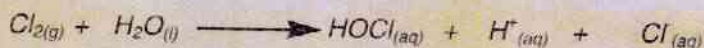
(iii) *Control of toxic chemicals:* Chemical contamination can cause acute illness, but often toxic contaminants are slow poisons and carcinogens. There must be a strict control over the use of pesticides and other chemicals.

Test yourself 15.4

i. Define waterborne diseases
ii. What is dysentery?
iii. Which bacteria causes the cholera?
iv. What do you mean by fluorosis?
v. What is hepatitis?

Chemistry of swimming pool cleanliness

Swimming pools are cleaned by chlorination process. It is the addition of chlorine solution in swimming pools. Chlorine kills bacteria and other micro-organisms. Cl_2 itself does not kill rather it dissociate in water to form hypochlorous acid (HOCl) and hydrochloric acid

$$Cl_{2(g)} + H_2O_{(l)} \longrightarrow HOCl_{(aq)} + H^+_{(aq)} + Cl^-_{(aq)}$$

HOCl further ionizes to produce hypochlorite and proton

$$HOCl_{(aq)} \longrightarrow H^+_{(aq)} + OCl^-_{(aq)}$$

Both the products HOCl and OCl^- kill bacteria and micro-organisms.

Key Points

- Water is an excellent solvent, has high specific heat capacity, high surface tension and high capillary action.
- Water is universal solvent because of its polarity and hydrogen bonding ability.
- Soft water produces lather with soap.
- Hard water does not produce lather with soap.
- Hardness is of two types: temporary and permanent.
- Temporary hardness is because of bicarbonates of calcium and magnesium. This hardness can be removed by boiling or by addition of slaked lime ($Ca(OH)_2$) in water.
- Permanent hardness is because of presence of carbonates and sulphates of calcium and magnesium. This hardness can be removed by treating water with washing soda and sodium zeolite.
- Used water is called waste water or sewage.
- Water pollution is caused by affecting water quality by pollutants.
- Industrial effluents are one of the main causes of water pollution. It includes high toxic organic chemicals, inorganic salts, heavy metals, mineral acids, oil and greases, etc.

- Household water in the sewage from toilets, baths, kitchens, etc. consists of detergents used for cleaning purposes. Detergent being non-biodegradable causes rapid growth of aquatic plants. When these plants die and decay, they consume O_2 present in the water. Thus, aquatic life is badly affected because of scarcity of O_2.
- Agricultural effluents consist of fertilizers and pesticides. These substances provide nitrate and phosphate ions for rapid growth of aquatic plants. When these plants die and decay, their decomposition process consumes O_2 of water. Thus, depletion of O_2 causes damage to the aquatic life.
- Waterborne diseases are those diseases that spread because of drinking polluted water. These diseases spread because of lack of proper sanitation arrangements. These diseases can be prevented by using safe water, properly disposing sewage and controlled use of toxic chemicals.

SKILLS

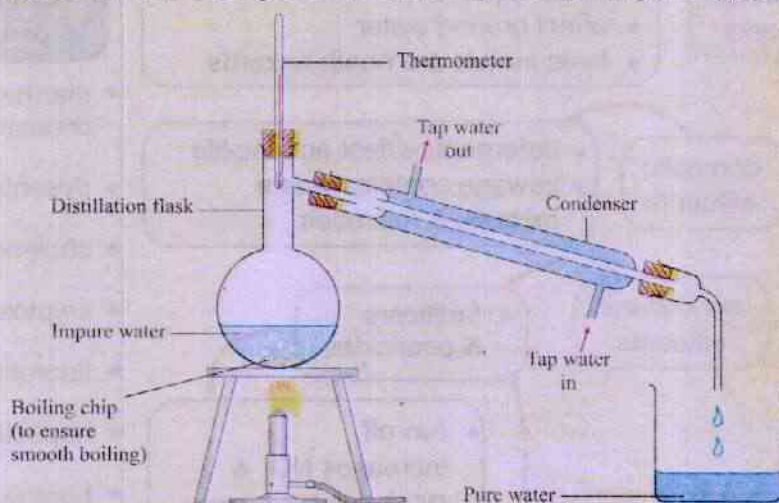
Quality of Water

Good quality water is colourless, odourless and tasteless. Hardness of water can be checked by washing. Soft water produces lather with water. Pure water has least conductivity.

Boiling point of water

Water boils at 100°C.

Distillation of impure water

Impure water can be purified by simple distillation apparatus as shown in figure. Distillation process involves boiling of a liquid and then condensing the vapours.

Impure water is taken in a distillation flask. It is boiled. Water vapours rise and enter the condenser. The vapours condense while passing through condenser. Thus, they are changed back into pure water, which is called distillate (distilled water). The distillate is collected in a beaker.

The impurities remains behind in the distillation flask.

CONCEPT DIAGRAM
hydrogen bonding ability
polarity of water
makes
WATER UNIVERSAL SOLVENT
dissolves salts of Mg^{2+} & Ca^{2+} with Cl^-, SO_4^{2-} HCO_3^- & CO_3^{2-}
causes hardness
temporary hardness because of HCO_3^- of Mg^{2+} & Ca^{2+}
removal by
boiling
Clark's method
permanent hardness because of SO_4^{2-} & Cl^- of Mg^{2+} & Ca^{2+}
removal by
using washing soda
using sodium zeolite
disadvantages
• hampers washing
• causes stomach disorders
• forms scales in boilers etc.
WATER POLLUTION
industrial effluents
• deteriorate quality of water
• affect aquatic life
• affect ground water
• toxic metals are heath hazards
domestic effluents
• detergents-affect aquatic life
• sewage contains waste material & microbes
agricultural effluents
• fertilizers & pesticides
• run-off increases NO_3^- & PO_4^{3-} in inland water.
• leaching increases NO_3^- in ground water.
effects
• hazard to human health, animals & birds.
• affects aquatic life.
• reduces aesthetic quality
• unfit for drinking & washing
waterborne diseases
• diarrheal diseases
• dysentery
• cholera
• cryptosporidium
• fluorosis
• hepatitis
• hookworm
• jaundice
• typhoid

EXERCISE

Multiple Choice Questions

Put a (✓)on the correct answer

1. **Which one of the following properties of water is responsible for rising of water in plants?**
   a. specific heat capacity b. surface tension
   c. excellent solvent action d. capillary action
2. **Specific heat capacity of water is:**
   a. 4.2 $kJg^{-1}K^{-1}$ b. 4.2 $Jg^{-1}K^{-1}$
   c. 2.4 $kJg^{-1}K^{-1}$ d. 2.4 $Jg^{-1}K^{-1}$
3. **Water dissolves non-ionic compound by:**
   a. ion-ion forces b. ion-dipole forces
   c. dipole-dipole forces d. hydrogen bonding
4. **Temporary hardness is because of :**
   a. $Ca(HCO_3)_2$ b. $CaCO_3$
   c. $MgCO_3$ d. $MgSO_4$
5. **Temporary hardness is removed by adding :**
   a. quick lime b. slaked lime
   c. limestone d. lime water
6. **Permanent hardness is removed by adding:**
   a. Na_2 zeolite. b. soda lime.
   c. lime water. d. quick lime.
7. **Which one of the following salts makes the water permanently hard?**
   a. Na_2CO_3 b. $NaHCO_3$
   c. $Ca(HCO_3)_2$ d. $CaSO_4$
8. **Rapid growth of algae in water bodies is because of detergent having**
   a. carbonate salts. b. sulphonic acid salts.
   c. sulphate salts. d. phosphate salts.
9. **Depletion of O_2 from water is not because of:**
   a. decaying of aquatic plants. b. biodegradation of aquatic plants.
   c. rapid growth of aquatic plants. d. decomposition of aquatic plants.

10. **Which one of the following diseases causes liver inflammation?**
    a. typhoid b. jaundice
    c. cholera d. hepatitis

11. **Which one of the following diseases causes severe diarrhea and can be fatal?**
    a. jaundice b. dysentery
    b. cholera d. typhoid

12. **Which one of the following gases is used to destroy harmful bacteria in water?**
    a. iodine b. chlorine
    c. fluorine d. bromine

13. **Which one of the following ions does not cause hardness in water?**
    a. Ca^{2+} b. Mg^{2+}
    c. SO_4^{2-} d. Na^+

14. **A disease that causes bone and tooth damage is:**
    a. fluorosis. b. hepatitis.
    c. cholera. d. jaundice.

15. **Ionic compounds are soluble in water due to:**
    a. hydrogen bonding. b. ion-dipole forces.
    c. dipole-dipole forces. d. dipole-induced dipole forces.

16. **The chemicals used to kill or control pests are called pesticides. They are:**
    a. dangerous inorganic chemicals. b. dangerous organic chemicals.
    c. beneficial inorganic chemicals. d. beneficial organic chemicals.

Short Questions

1. How water rises in plants?
2. Which forces are responsible for dissolving polar substances in water?
3. Why non-polar compounds are insoluble in water?
4. How water dissolves sugar and alcohols?
5. How limestone dissolves in water?
6. Differentiate between soft and hard water.

7. What are the causes of hardness in water?
8. What are the effects of temporary hardness in water?
9. Mention the disadvantages of detergents.
10. What is difference between biodegradable and non-biodegradable substances?
11. How detergents make the water unfit for aquatic life?
12. Why are pesticides used?
13. What are the reasons of waterborne diseases?
14. How waterborne diseases can be prevented?

Extensive Questions

1. How polarity of water molecule plays its role to dissolve the substances?
2. Explain the methods of removing permanent hardness.
3. Explain the water pollution because of industrial waste.
4. Justify the statement: household water is the reason of water pollution.
5. Explain agricultural effluents are fatal for aquatic life.
6. Explain five important waterborne diseases. How can these be prevented?
7. Give some disadvantages of hard water.
8. What is water pollution? Describe the effects of using polluted water.
9. Explain the reasons, why is water considered a universal solvent.
10. Write a note on the treatment of sewage water.

Chapter 16

Chemical Industries

Major Topics

16.1 Basic Metallurgical Operations
16.2 Solvay's Process
16.3 Urea
16.4 Petroleum Industry

Time allocation

Teaching periods	13
Assessment periods	03
Weightage	9%

Students Learning Outcomes

Students will be able to:

- describe some metallurgical operations. (Applying);
- make a list of raw materials for Solvay process. (Applying);
- outline the basic reactions of Solvay process. (Analyzing);
- develop a flow sheet diagram of Solvay process. (Creating);
- describe the composition of urea. (Understanding);
- develop a flow sheet diagram for the manufacture of urea. (Creating);
- list the uses of urea. (Remembering);
- define petroleum. (Remembering);
- describe the formation of petroleum and natural gas. (Understanding);
- describe the composition of petroleum. (Remembering);
- describe briefly the fractional distillation of petroleum. (Applying).

Introduction

Chemical industries are established to meet the needs of modern societies. Metallurgy is the science of extracting metals from ores. Metals have played a major role in progress of societies. Since ages metals are used for making tools, machines and other items. In the modern age, although polymers have taken the place of metals, yet the importance of metals cannot be ignored.

Baking soda ($NaHCO_3$) and washing soda (Na_2CO_3) are used in daily life for different purposes. Solvay's process for the manufacturing of baking and washing soda from common salt will be discussed in detail.

Fertilizers are vital for the growth and development of plants and crops. One of the important fertilizers urea, is used to enhance the productivity of crops. Hence, the synthesis of urea has been explained here.

In the modern age of communication, petroleum industry has a great significance. Petroleum products are used as fuel, solvent and lubricants. Petrochemicals are used to manufacture a variety of household items, plastics, detergents, rubber, etc.

Pakistan industrial base was very weak at the time of independence. At the time of partition, there were 921 big industrial units in India, out of these only 34 came to the share of Pakistan.

After the independence, government made a lot of policies and encouraged the private sector to establish industrial units. Chemical industry was rapidly developed because the chemicals are used for the manufacturing of ammunitions, fertilizers and other substances of daily use.

A lot of steps and measures are taken to set up corporations to facilitate loans and technical know-how for the rapid development of industries. Pakistan is now producing chemicals, fertilizers, cement, steel, heavy engineering machines and tools.

16.1 BASIC METALLURGICAL OPERATIONS

First of all let's leave definitions of terms used in metallurgical operations.

Minerals

The solid natural materials found beneath the Earth's surface, which contains compounds of metals in the combined state along with earthly impurities, are called minerals.

Ores

Those minerals from which the metals are extracted commercially at a comparatively low cost with minimum effort are called ores of the metals. For example: ores of copper are; copper glance (Cu_2S) and chalcopyrite ($CuFeS_2$).

Hence, all ores of the metals are minerals, but all minerals are not ores.

Interesting Information

The colour of hair is caused by the presence of transition metal compounds in the hair. Brown hair contains iron or copper compounds, blonde hair contains compounds of titanium and redhead hair is because of the presence of molybdenum compounds.

Gangue

The earthly and other impurities associated with the minerals are known as gangue.

Metallurgy

The process of extraction of a metal in a pure state on a large scale from its ore by physical or chemical means is called metallurgy.

The processes involved in metallurgy for extraction of a metal in the pure state from its ore are:

(i) concentration of the ore;

(ii) extraction of the metal, and

(iii) refining of the metal.

(i) Concentration of the Ore

The process of removal of gangue from the ore is technically known as concentration and the purified ore is called the concentrate. Concentration of the crushed ore is carried out by the following methods:

(a) Gravity separation

Gravity separation is based on the differences in densities of the metallic ore and the gangue particles.

In the process, the powdered heavy metal bearing ore settles down on agitation in a stream of water, while the lighter gangue particles are carried away by the water as shown in figure 16.1.

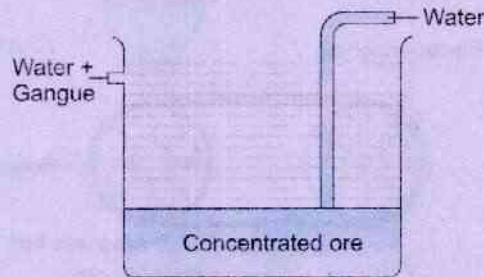



Fig. 16.1 Gravity separation

(b) Froth flotation process

Froth flotation process is based on the wetting characteristic of the ore and the gangue particles with oil and water, respectively.

The ore particles are preferentially wetted by oil and the gangue particles by water. The whole mixture is agitated with compressed air. Hence, oil coated ore particles being lighter come to the surface in the form of froth that can be skimmed as shown in figure 16.2.

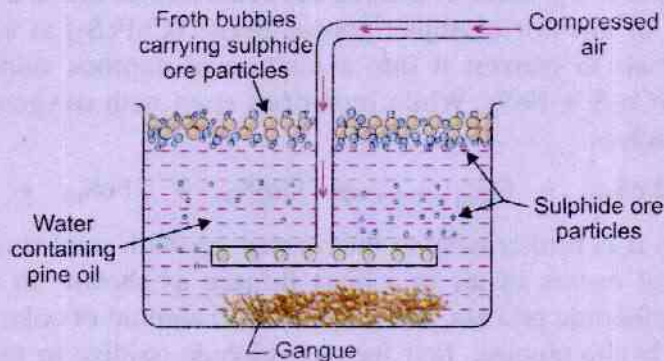



Fig. 16.2 Froth flotation process

(c) Electromagnetic separation

Electromagnetic separation is based on the separation of magnetic ores from the non-magnetic impurities by means of electro-magnets or magnetic separators.

The powdered ore is dropped over a leather belt moving over two rollers, one of which is magnetic. The non-magnetic ore falls first and the magnetic ore gets attracted and falls farther away as shown in figure 16.3.

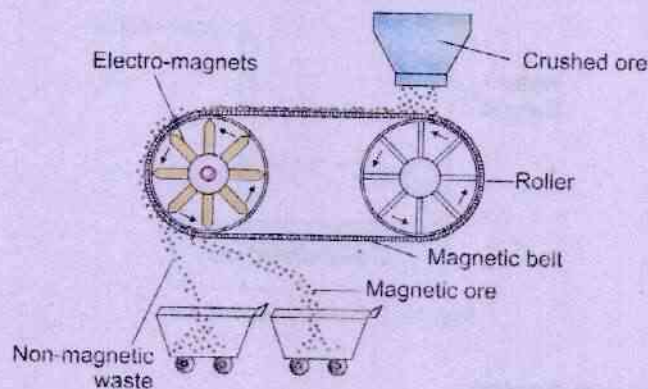



Fig 16.3: Magnetic separation

(ii) Extraction of the metal from the concentrated ore

The metal is isolated from the concentrated ore by chemical reduction or electrolytic processes.

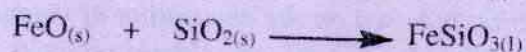
Chemical methods of reduction of ore involves following methods:

(a) **Roasting:** It is a process of heating the concentrated ore to a high temperature in excess of air. For example; copper pyrite ($CuFeS_2$) is strongly heated in excess of air to convert it into a mixture of cuprous sulphide and ferrous sulphide ($Cu_2S + FeS$). While impurities react with oxygen to form volatile oxides. Such as

$$2CuFeS_{2(s)} + O_{2(g)} \longrightarrow Cu_2S_{(s)} + 2FeS_{(s)} + SO_{2(g)}.$$

(b) **Smelting:** It is further heating the roasted ore with sand flux and coke in the presence of excess of air in a blast furnace as shown in figure 16.4. It is highly exothermic process, therefore, a small amount of coke is required in the process. In the process, first ferrous sulphide oxidize to form ferrous oxide which reacts with sand to form iron silicate slag ($FeSiO_3$). It being lighter rise to the top and is removed from the upper hole.

$$2FeS_{(s)} + 3O_{2(g)} \longrightarrow 2\,FeO_{(s)} + 2SO_{2(g)}\uparrow$$

$$FeO_{(s)} + SiO_{2(s)} \longrightarrow FeSiO_{3(l)}$$

On the other hand, cuprous sulphide also oxidize to form cuprous oxide which reacts with unreacted ferrous sulphide to form ferrous oxide and cuprous sulphide. In this way, cuprous sulphide and ferrous sulphide form a mixture ($Cu_2S.FeS$). This molten mixture is called matte.

It is withdrawn from the lower hole. It contains about 45% of copper.

$$2Cu_2S_{(s)} + 3O_{2(g)} \longrightarrow 2Cu_2O_{(l)} + 2SO_{2(g)}\uparrow$$

$$Cu_2O_{(s)} + FeS_{(s)} \longrightarrow Cu_2S_{(s)} + FeO_{(s)}$$

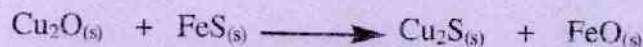
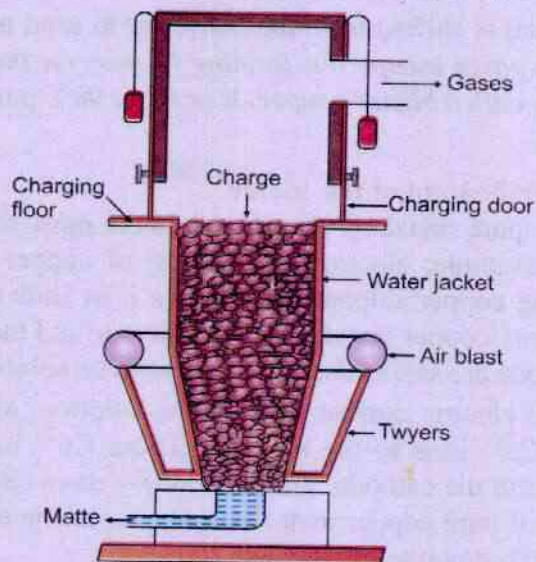
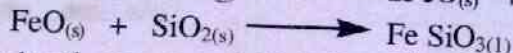



Fig. 16.4 Blast furnace for smelting of copper

(c) **Bassemerization:** It is the further heating of the molten matte in a pear shaped bessemer converter as shown in figure 16.5. It is fixed on a pivot, so that it can be tilted in any direction. Molten matte is mixed with sand and heated with a hot blast of air through twyers. Ferrous sulphide is oxidized to form ferrous oxide. Which reacts with sand to form slag ($FeSiO_3$) that floats on the top.

$$2FeS_{(s)} + 3O_{2(g)} \longrightarrow 2FeO_{(s)} + 2SO_{2(g)}$$
$$FeO_{(s)} + SiO_{2(s)} \longrightarrow Fe\,SiO_{3(l)}$$

On the other hand, cuprous sulphide is oxidized to form cuprous oxide, which again reacts with remaining cuprous sulphide to form metallic copper.

$$2Cu_2S_{(s)} + 3O_{2(g)} \longrightarrow 2Cu_2O_{(l)} + 2SO_{2(g)}\uparrow$$
$$2Cu_2O_{(s)} + Cu_2S_{(s)} \longrightarrow 6Cu_{(l)} + SO_{2(g)}\uparrow$$

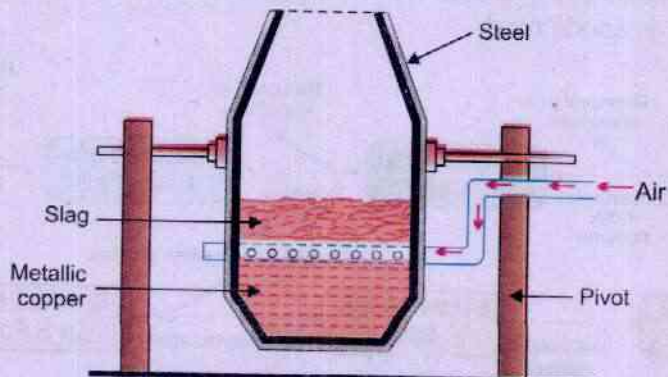



Fig. 16.5 Bessemer converter used for bessemerization of copper.

The molten metal is shifted from the converter to sand moulds and is allowed to cool. *The dissolved gases escape out forming blisters on the surface of the solid copper. Therefore, it is called* ***blister copper***. It is about 98% pure copper. It is further refined by electrolysis.

(iii) Refining or purification of the metal

Refining the impure metal by electrolysis is the most widely used process of refining metals. For example, electrolytic refining of copper is carried out in an electrolytic tank having copper sulphate solution in it as shown in figure 16.6. Two electrodes; one of impure copper metal that acts as anode and the other of pure copper metal that acts as cathode are suspended in the electrolytic solution.

On passing the electric current through the solution, anode (impure copper) dissolves to provide Cu^{2+} ions to the solution. These Cu^{2+} ions are discharged by gaining of electrons from the cathode. *Thereby copper atoms deposit on the cathode*, making it thick block of pure copper metal as is shown in figure 16.6. The impurities like gold and silver settle down as anode mud.

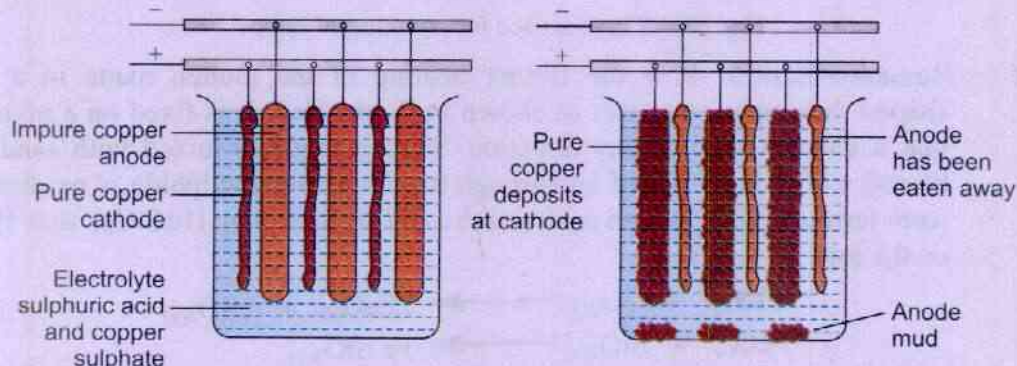



Fig. 16.6 Electro-refining of copper.

In the process, impure copper from the anode dissolves and goes into the copper sulphate solution. Side by side, pure copper ions from the solution deposit on the cathode. Thus, cathode becomes a pure copper metal. The impurities like gold and silver settle down as anode mud

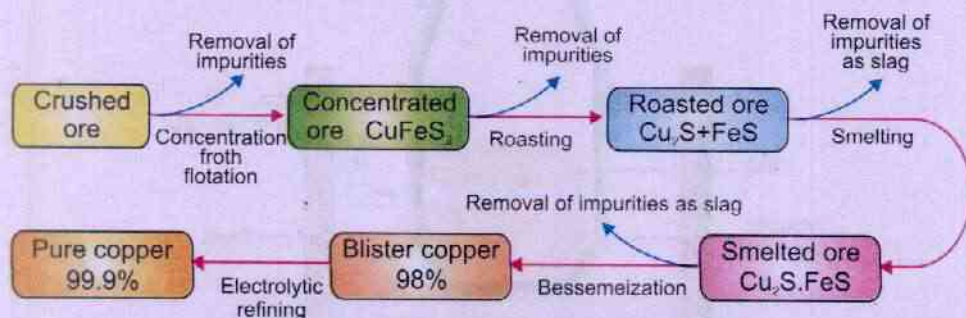



Fig. 16.7 Flow sheet diagram for extraction of copper

i. Define concentration process used in metallurgy of copper.
ii. Why a small amount of coke is required in the smelting process? How is slag formed during smelting.
iii. Why is lime added in the smelting process?
iv. How are slag and matte removed from the blast furnace?
v. What is difference between slag and matte?
vi. Mention the chemical reactions for the formation of metallic copper in the bessemerization process.
vii. What is blister copper?
viii. Why anode is eaten up in electro-refining process?
ix. What do you mean by anode mud?

16.2 MANUFACTURE OF SODIUM CARBONATE BY SOLVAY'S PROCESS

Principle of Solvay's process lies in the low solubility of sodium bicarbonate at low temperature i.e. at 15°C. When CO_2 is passed through an ammonical solution of NaCl called ammonical brine only $NaHCO_3$ precipitates.

$$Na^+_{(aq)} + HCO_3^-{}_{(aq)} \longrightarrow NaHCO_{3(s)}$$

16.2.1 Raw Materials

The raw materials needed for this process are cheap and easily available. They are in abundance, such as,

(i) Sodium chloride (NaCl) or brine.

(ii) Limestone ($CaCO_3$).

(iii) Ammonia gas (NH_3).

16.2.2 Basic Reactions

The process consists of the following steps:

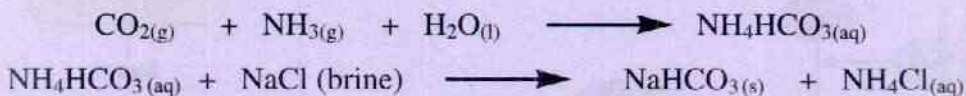
(i) Preparation of ammonical brine:

First of all ammonical brine is prepared by dissolving ammonia gas in sodium chloride solution (brine).

(ii) Carbonation of ammonical brine:

Ammonical brine is fed into carbonating tower and carbon dioxide is passed through it. Following reactions take place in the carbonating tower.

$$CO_{2(g)} + NH_{3(g)} + H_2O_{(l)} \longrightarrow NH_4HCO_{3(aq)}$$

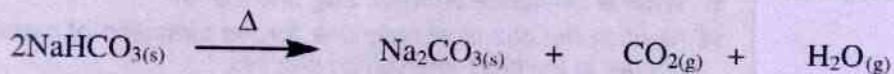
$$NH_4HCO_{3\,(aq)} + NaCl\ (brine) \longrightarrow NaHCO_{3\,(s)} + NH_4Cl_{(aq)}$$

The temperature of the mixture is lowered to 15°C and precipitates of $NaHCO_3$ are obtained.

(iii) Filtration of precipitates:

The milky solution from the carbonating tower is filtered to get sodium bicarbonate. It is used as a baking soda.

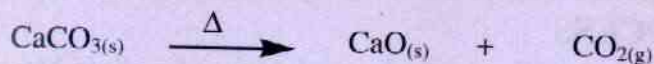
(iv) Calcination:

Sodium carbonate is heated to get sodium carbonate.

$$2NaHCO_{3(s)} \xrightarrow{\Delta} Na_2CO_{3(s)} + CO_{2(g)} + H_2O_{(g)}$$

CO_2 is again used in tower. It is about half of CO_2 needed in the process.

(v) Preparation of carbon dioxide and slaked lime:

CO_2 is prepared by heating limestone in a lime kiln. Then it is carried to carbonating tower

$$CaCO_{3(s)} \xrightarrow{\Delta} CaO_{(s)} + CO_{2(g)}$$

Quick lime (CaO) formed in lime kiln is slaked with water. Then, it is pumped to the ammonia recovery tower.

$$CaO_{(s)} + H_2O_{(l)} \longrightarrow \underset{\text{(slaked lime)}}{Ca(OH)_2}$$

(vi) Ammonia recovery tower:

Ammonia is recovered in this tower from ammonium chloride solution produced in the carbonated tower and calcium hydroxide formed in lime kiln.

$$2NH_4Cl_{(aq)} + Ca(OH)_{2(aq)} \longrightarrow 2NH_{3(g)} + CaCl_{2(aq)} + 2H_2O_{(l)}$$

In fact, all ammonia is recovered in this tower and is reused in the process. There are minor losses of ammonia in the process which are compensated by using some fresh ammonia.

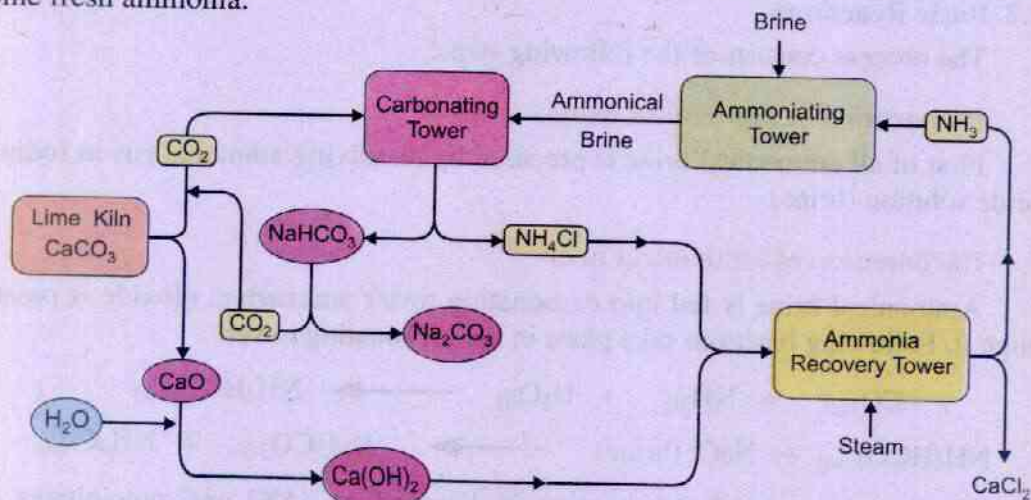



Fig. 16.8: Flow sheet diagram of Solvay's Process for the manufacturing of sodium carbonate.

Advantages of Solvay's process

(i) It is a cheap process as raw materials are available at very low prices.

(ii) Carbon dioxide and ammonia are recovered and reused.

(iii) Process is pollution free, because the only waste is calcium chloride solution.

(iv) Sodium carbonate of very high purity is obtained.

(v) Consumption of fuel is very less since no solution is to be evaporated.

Pakistan is self-sufficient as far as demand of sodium carbonate is concerned.

Imperial Chemical Industries (ICI) Khewra (Jhelum) is producing enough sodium carbonate. This unit was established in 1944 in Khewra because abundant raw material sodium chloride is available here. Sindh alkalies limited was established near Karachi in 1966.

Sodium carbonate and sodium bicarbonate are important industrial chemicals and are used by many industries.

Test yourself 16.2

i. Why only $NaHCO_3$ precipitates, when CO_2 is passed through the ammonical brine?

ii. Which raw materials are required for the formation of sodium carbonate?

iii. How is CO_2 prepared in the Solvay's process?

iv. Give the reaction of formation of ammonia in the process.

v. Give the advantages of Solvay's process.

SOCIETY TECHNOLOGY SCIENCE

Role of technology in the production of common chemicals.

Technology is considered a consequence of science and engineering.

Common chemicals such as acids, alkalies, salts, soaps, detergents, etc. are being produced on commercial scale by chemists or chemical engineers since centuries. Technology began to influence human efforts to produce common chemicals since people began using different tools and machineries.

Now it is because of use of technology that needs of people are being fulfilled. Use of technology has increased the production with improved quality of products.

16.3 Manufacture of Urea

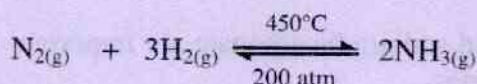
Urea is nitrogenous fertilizer. It consists of 46.6% nitrogen. It is white crystalline compound, highly soluble in water. It is used for the manufacturing of important chemicals, but its major (about 90%) use is as a fertilizer.

16.3.1 Raw Material

The raw materials for the manufacturing of urea are:

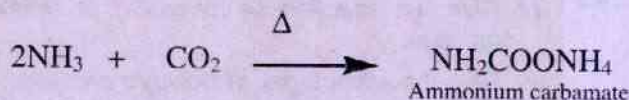
(i) Ammonia (NH_3) (ii) Carbon dioxide (CO_2)

Ammonia is prepared by the "Haber's process". One volume of nitrogen (from air) and three volumes of hydrogen (obtained by passing methane and steam over heated nickel catalyst) is passed over iron catalyst at 450°C and 200 atm pressure.

$$N_{2(g)} + 3H_{2(g)} \underset{200\text{ atm}}{\overset{450°C}{\rightleftharpoons}} 2NH_{3(g)}$$

16.3.2 Process

Manufacturing of urea involves three stages:

(i) **Reaction of ammonia and carbon dioxide:** Carbon dioxide is passed through liquid ammonia under high pressure to form **ammonium carbamate**

$$2NH_3 + CO_2 \xrightarrow{\Delta} \underset{\text{Ammonium carbamate}}{NH_2COONH_4}$$

(ii) **Urea formation**: When ammonium carbamate is evaporated with the help of steam, it dehydrates to form urea.

$$NH_2COONH_4 \longrightarrow \underset{\text{(Urea)}}{NH_2CONH_2} + H_2O\uparrow$$

(iii) **Granulation of urea**: At this stage, liquid urea is evaporated to form granules. When liquid urea is sprayed from top of a tower under pressure and a hot current of air is introduced from the base, it evaporates to form granules. This is stored to be marketed.

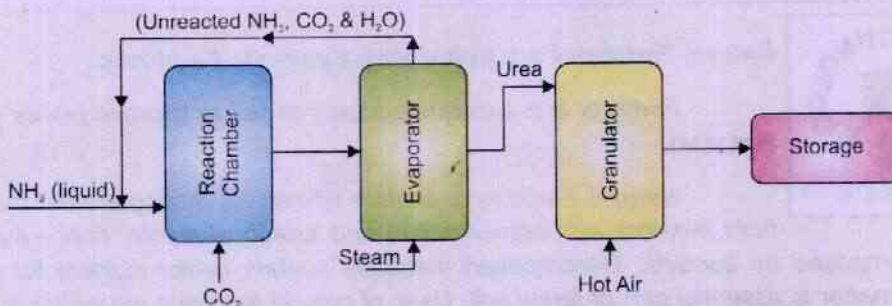



Fig. 16.9 Flow sheet diagram of Urea

Importance and Status of Urea

It is white crystalline organic compound. Its importance is because of following usage:

(i) Urea is widely used world over in the agriculture sector both as a fertilizer and animal feed additive. About 90% of urea is used as fertilizer. It has the highest nitrogen percentage, i.e. much higher than other nitrogenous fertilizers. It is harmless and is useful for all types of crops and soils.

It is non-toxic, non-explosive, therefore, can be stored safely. But it is very soluble in water and hygroscopic, therefore, storage requires better packing.

(ii) It is used as a raw material for the manufacture of many important compounds.

(iii) It is used to make explosives.

(iv) It is used in automobile systems to reduce the NO_x pollutants in exhaust gases.

There are about six urea manufacturing units in Pakistan. The major four are Fauji Fertilizer company; Engro Chemicals; Fauji Fertilizer, Bin Qasim and Dawood Hercules company. Fauji Fertilizer is the biggest fertilizer manufacturer with 59% market shares.

Government provides an indirect subsidy to manufacturers but this industry is still facing supply shortfall problems. The price of urea has grown since the last years.

Test yourself 16.3

i. *What happens when ammonium carbamate is heated with steam?*

ii. *How many stages are involved in the formation of urea?*

iii. *What is the percentage of nitrogen in urea?*

Interesting Information

Crops need phosphorus and nitrogen to grow well. Although, there is 78% nitrogen in air yet it can't be assimilated directly by plants. Therefore, fertilizers are used to provide these essential elements to soil and ultimately plants.

Natural Fertilizers are better than Synthetic Fertilizers.

Fertilizer is a substance added to soil to improve plants' growth and yield.

***Natural Fertilizers** contain all natural biodegradable materials from livestock and human waste and foliage of plants. These materials are decomposed by bacteria. Decomposed materials contain useful nutrient for plants. Organic matter is essential part of fertile soil. Uses of natural fertilizers return the nutrients and organic matter of soil.*

They improve the soil condition to support plant growth.

- *They improve the porosity of the soil to make it capable of absorbing water. Thus improves crops production.*
- *They improve the structure of soil which in turn allows more air to get to plant roots.*
- *The chance of water shortage because of the moisture holding capacity of soil increases.*
- *Natural fertilizers practically do not contain toxic chemicals. Thus, they do not damage the soil and crops yield increase.*

***Chemical Fertilizers** include one or more of the three elements most important for plant nutrition; nitrogen, phosphorus and potassium.*

- *They release the nutrients very fastly.*
- *Their effects are short lived, so they are required again and again, after short intervals may be 4 to 6 times in a year.*
- *Use of synthetic fertilizers may cause over fertilization resulting in burning of plants instead of greening them.*

16.4 PETROLEUM INDUSTRY

16.4.1 Petroleum

Petroleum is a natural product found under the Earth's crust trapped in rocks. Petroleum means rock oil. *It is a complex mixture of several gaseous, liquid and solid hydrocarbons having water, salts and earth particles with it.* It is lighter than water and is insoluble in it.

16.4.2 Origin of Petroleum

Petroleum was formed by the decomposition of dead plants and animals buried under Earth's crust millions of years ago. It is believed that millions of years ago living plants and animals in the seas died. Their bodies sank and buried under

mud and sand. Then decomposition process took place in the absence of air because of high pressure, temperature and bacterial effects. This process took millions of years for completion. *Thus, remains of dead plants and animals were converted into a dark brownish viscous **crude oil.*** It was trapped between two layers of impervious rocks, as shown in figure 16.10.

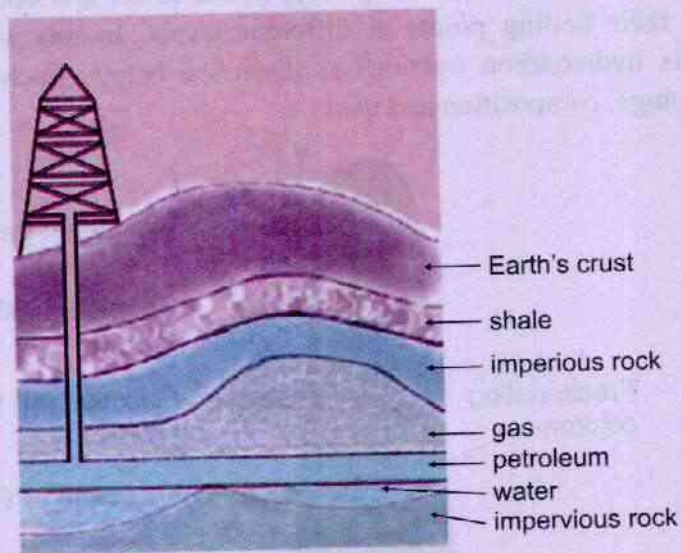



Fig. 16.10 Occurrence of petroleum

Being lighter and insoluble in water it floats over the water and forms an oil trap. The gaseous products accumulated over the petroleum are found as natural gas.

Petroleum is extracted by drilling holes (oil wells) into Earth's crust where the oil is found. When a well is drilled through the rocks, natural gas comes first with a great pressure. For some time crude oil also comes out by itself due to gas pressure. When gas pressure subsides, then crude oil is pumped out.

The crude oil is refined in the refineries. ***Refining** process is the separation of crude oil mixture into various useful products (fractions).* It is carried out by a process called **fractional distillation**. The principle of fractional distillation is based upon separation of substances depending upon their boiling points. The substances having low boiling points boil out first, leaving behind others. Then next fraction of slightly higher boiling point boils out. This process remain continue until a residue is left behind. The vapours of each fraction are collected and condensed separately.

The fractional distillation of petroleum is carried out in a tall fractionating tower as shown in figure 16.11.

The crude oil is heated in a furnace upto a temperature of 400°C under high pressure. Then vapours are passed through a fractionating column from near its bottom as shown in figure 16.11. Hot vapours rise up in the column and gradually cools down and condense. Such that vapours of higher boiling point fraction (350—400°C) condense first in the lower part of the tower, while vapours of medium and lower boiling point fractions rise upwards in the tower and condense gradually with respect to their boiling points at different levels. In this way, crude oil is separated into six hydrocarbon fractions as discussed below. Each fraction has its specific boiling range, composition and uses.

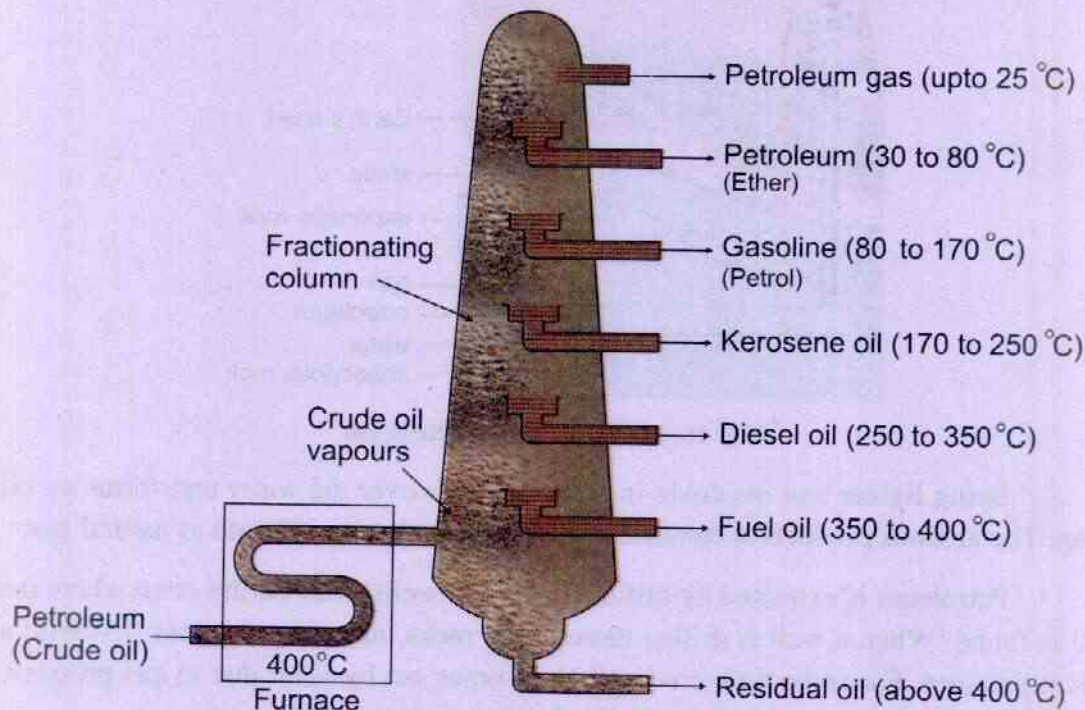



Fig 16.11 Fractional distillation of petroleum.

16.4.3 Important Fractions of Petroleum

Each fraction is not a single compound. Rather each one is a mixture of hydrocarbons having different number of carbon atoms in it. The name of each fraction, its molecular composition, boiling range and uses are given in the following table 16.2:

Table 16.2 Fractions of Petroleum

Name	Composition	Boiling range	Uses
Petroleum Gas	C_1 to C_4	up to 25°C	As a fuel, as such in the form of LPG, used for the production of carbon black (needed in tyre industry) and hydrogen gas (needed to form NH_3 used to manufacture fertilizer).
Petroleum Ether	C_5 to C_7	30 to 80°C	Used as laboratory solvent and for dry cleaning purposes.
Gasoline or Petrol	C_7 to C_{10}	80 to 170°C	Used as fuel in motor cycles, motor cars and other light vehicles. It is more volatile than kerosene oil. It is also used for dry cleaning.
Kerosene oil	C_{10} to C_{12}	170 to 250°C	Used as domestic fuel, a special grade of it is used as jet fuel.
Diesel oil	C_{13} to C_{15}	250 to 350°C	Fuel for buses, trucks railway engines, tubewell engines and other heavy vehicles.
Fuel oil	C_{15} to C_{18}	350 to 400°C	Used in ships and industries to heat boilers and furnaces.

The **residual oil,** which does not vapourize under these conditions is collected and heated above 400°C for further fractional distillation. The four fractions of residual oil are:

lubricants; paraffin wax; asphalt and petroleum coke.

Test yourself 16.4

i. Define petroleum.

ii. How is petroleum extracted?

iii. What is principle of fractional distillation?

iv. In how many fractions crude oil is separated?

v. What do you mean by a fraction of petroleum?

Interesting Information

The diesel fuel sold in winter is different mixture of hydrocarbons from the mixture sold in summer. This is because diesel sets rather like Vaseline at a little below 0 °C and will not work as a fuel. More of the lighter fractions are added in winter to prevent this.

Different types of fire require different methods to extinguish.

The things needed to start and sustain fire are:

Fuel: The substance that burns in the combustion process, e.g. wood, oil and electricity.

Heat: The energy component of the fire when it comes in contact with fuel, it provides the energy necessary for ignition and sustaining combustion process.

Air(oxygen): it is essential component for combustion process.

A self sustained chemical chain reaction is a complex reaction that requires fuel, oxygen and heat energy to come together in a very specific way.

Fire can be put out by taking away any of the above-mentioned components. When fuels are different, they require different techniques to put them out.

Wood fire can be extinguished by throwing water on it. Water uses large amount of heat for evaporation process, so it absorbs huge amount of heat and deprive the wood fire of heat and it is not possible for fire to be sustained.

Oil fires can't be put out with water because oil and water do not mix. Oil being lighter than water, floats and spreads over it. The fire also spreads along with water. To put out oil fire, oxygen needs to be cut off. This can be controlled by throwing sand, table salt or baking soda on the flames.

Electric fire is much stronger than other fires because its source of heat is electrical energy. It requires cut off oxygen supply to put it out. Oxygen supply can be controlled by using fire extinguishers.

Chemistry as a career in industry.

By studying chemistry one can be a professional chemist. He studies the composition and properties of available chemicals. Then he develops methods to manufacture new substances on commercial scale to meet the needs of society. He also designs and develops instruments and techniques to make the production more and more economical.

Chemists can have working opportunities in almost all fields of industry depending upon their areas of specialization.

Organic chemists have career in pharmaceutical, petroleum, petrochemicals, cosmetic, polymer and plastic industries.

Inorganic chemists work in metallurgical industries; manufacturing industries like textile, cement, sugar and chemicals; manufacturing plants like fertilizer, acids and caustic soda.

Physical chemists have working opportunities in energy transformation industries. They develop new and better energy sources. They explore renewable energy fields.
Analytical chemists work in almost all fields of industry. They identify the materials, measure their quantities and control the quality of the products. They evaluate the efficiency and devise techniques to enhance the production. They have working scope from food and beverage industry to paints and varnish industry. They work even in generating units. Besides these major career opportunities there are many other types of chemists such as biochemists, food chemists, material chemists, etc.

Good communication skills promote the sale.

Communication is the exchange of information to others through audio, video, print or electronic media.

Good **communication skills** help ensure the efficient operation of all levels of an organization, from lowest to highest, whereas poor communication skills often result in inefficiency. Successful business leaders know, inefficiency equals a loss of productivity and consequently, a loss of profits.

Moreover, communication can make the difference between success and failure for a company. Therefore, in the field of chemical industry good communication skills are also vital.

Key Points

- Metallurgy is technique by which metals are extracted from their ores.
- Concentration is a separating technique in which mineral is separated from gangue.
- Sodium carbonate is manufactured by Solvay's process. The raw materials used in this process are sodium chloride, carbon dioxide and ammonia.
- Ammonical brine is prepared by dissolving ammonia gas in sodium chloride solution. When this solution is carbonated; first NH_4HCO_3 forms, which reacts with NaCl to form $NaHCO_3$.
- $NaHCO_3$ on heating produces Na_2CO_3.
- Urea is manufactured from ammonia and carbon dioxide. First Ammonia and carbon dioxide react to form ammonium carbamate. On evaporation, it dehydrates to form urea.
- Petroleum is a complex mixture of hydrocarbons. It forms by the decomposition of dead animals and plants buried under the Earth's crust.
- Crude oil is pumped out and then refined in the refineries. Refining is carried out by fractional distillation on heating crude oil at 400°C.
- The important fractions of petroleum are; petroleum gas, petroleum ether, petrol, kerosene oil, diesel and fuel oil.
- The residual oil is heated above 400°C to produce lubricants, paraffin wax, asphalt and petroleum coke.

CONCEPT DIAGRAM

Basic Metallurgical Operations

Concentration of Ore by

- Gravity separation
- Froth flotation process
- Electromagnetic separation

Extraction of Metal by

- Roasting
- Smelting
- Bessemerization

Refining of Metal by

- electrolysis
- anode - impure metal
- cathode - pure metal

Solvay's Process

Raw Materials
- Sodium chloride
- Lime stone
- Ammonia gas

Basic Reactions
- preparation of ammonical brine
- carbonation of ammonical brine
- separation of sodium bicarbonate
- preparation of carbon dioxide
- recovery of ammonia

- Advantages
- cheap raw materials
- pollution free
- produces pure product
- low consumption of fuel

Manufacture of Urea

Raw materials
- ammonia
- carbon dioxide

Process
- reaction of NH_3 & CO^2
- urea formation
- granulation of urea

Uses
- 90% use as fertilizer
- raw material for explosives

Origin of Petroleum

dead animals & plants

decomposition

crude oil

refining by fractional distillation up to 400°C

6 fractions of petroleum

- petroleum gas
- petroleum (Ether)
- gasoline (Petrol)
- kerosene oil
- diesel oil
- fuel oil

- residual oil

above 400°C

4 fractions of residual oil

- lubricants
- paraffin wax
- asphalt
- petroleum coke

EXERCISE

Multiple Choice Questions

Put a (✓)on the correct answer

1. **Concentration is a**
   a. mixing technique
   b. separating technique
   c. boiling technique
   d. cooling technique

2. **Froth flo tation process is used to concentrate the ore on:**
   a. density basis
   b. concentration basis
   c. wetting basis
   d. magnetic basis

3. **Matte is a mixture of:**
   a. FeS and CuS
   b. Cu_2O and FeO
   c. Cu_2S and FeS
   d. CuS and FeO

4. **In the bessemerization process:**
   a. roasted ore is heated
   b. molten matte is removed
   c. molten matte is heated
   d. molten matte is added

5. **Concentration of the copper ore is carried out by:**
   a. calcinations
   b. roasting
   c. forth flotation
   d. distillation

6. **When CO_2 is passed through the ammonical brine the only salt that precipitates is:**
   a. $NaHCO_3$
   b. NH_4HCO_3
   c. Na_2CO_3
   d. $(NH_4)_2CO_3$

7. **In Solvay's process slaked lime is used to:**
   a. prepare CO_2
   b. prepare quick lime.
   c. recover ammonia
   d. form Na_2CO_3

8. **When $NaHCO_3$ is heated it forms:**
   a. CO_2
   b. $Ca(OH)_2$
   c. $CaCO_3$
   d. CaO

9. **Formula of urea is:**
   a. NH_2COONH_4
   b. NH_2COONH_2
   c. NH_2CONH_4
   d. NH_2CONH_2

10. **Crude oil is heated in the furnace upto:**
    a. 300°C
    b. 350°C
    c. 400°C
    d. 450°C

11. **When heated crude oil is fed to the fractionating tower**
    a. vapours of higher boiling point fraction condense first in the lower part of the tower
    b. vapours of lower boiling point fraction condense first in the lower part of tower
    c. vapours of higher boiling point condense later in the upper part of tower
    d. vapours of higher boiling point never condense

12. **Which one of the following is used as jet fuel:**
    a. kerosene oil
    b. lubricating oil
    c. fuel oil
    d. diesel oil

13. **Which one of the following is not fraction of crude oil?**
    a. paraffin wax
    b. asphalt
    c. fuel oil
    d. petroleum coke

14. **Which one of the followings is not a fraction of petroleum?**
    a. kerosene oil
    b. diesel oil
    c. alcohol
    d. petrol

15. **The nitrogen present in urea is used by plants to synthesize**
    a. sugar
    b. proteins
    c. fats
    d. DNA

16. **Which one of the following organic compound is found in gasoline?**
    a. C_2H_4
    b. C_3H_8
    c. C_8H_{18}
    d. $C_{12}H_{26}$

Short Questions

1. What role is played by pine oil in the froth flotation process?
2. Name the various metallurgical operations.
3. How is roasting carried out?
4. Explain process of electrorefining.
5. What are the advantages of Solvay's process?
6. What is the principle of Solvay's process?

7. What happens when ammonical brine is carbonated?
8. How $NaHCO_3$ is converted to Na_2CO_3?
9. How is ammonia recovered in the Solvay's process?
10. How is ammonia prepared for the synthesis of urea?
11. Describe the formation of petroleum.
12. What is refining of petroleum and how it is carried out?
13. Give a use of kerosene oil.
14. Describe the difference between diesel oil and fuel oil.
15. Write down the names of four fractions obtained by the fractional distillation of residual oil.
16. What is the difference between crude oil and residual oil?
17. Which petroleum fraction is used in dry cleaning?

Extensive Questions

1. Describe in detail the various processes involved in the concentration of ore. Explain your answer with the help of diagrams.
2. Explain the process of roasting with reference to copper.
3. Write a detailed note on Ammonia Solvay's process.
4. Write a note on fractional distillation of petroleum.
5. How urea is manufactured? Explain showing the flow sheet diagram.
6. How crude oil is refined? Explain two important fractions of petroleum along with their usage.
7. Write a note in detail on smelting and bessemerization, giving a specific example.

ANSWERS

Chapter 9

Numericals

(1) 24.5 mol dm^{-3} (2) 0.019

(3) 1.09×10^{-5} (4) 0.14 mol dm^{-3}

Chapter 10

Numericals

(1) pH 0.4; pOH 13.6 (2) pH 13 (3) pH 2.4; pOH 11.6

(4)

	Solution	$[H^+]$	$[OH^-]$	pH	pOH
(i)	0.15 M HI	15×10^{-2}	—	0.82	13.12
(ii)	0.040 M KOH	—	4×10^{-2}	12.6	1.4
(iii)	0.020 M $Ba(OH)_2$	—	4×10^{-2}	12.6	1.4
(iv)	0.00030 M $HClO_4$	3×10^{-4}	—	3.52	10.48
(v)	0.55 M NaOH	—	55×10^{-2}	13.74	0.26
(vi)	0.055 M HCl	55×10^{-3}	—	1.26	12.74
(vii)	0.055 M $Ca(OH)_2$	—	11×10^{-2}	13.04	0.96

GLOSSARY

A

Acid rain is formed by dissolving acidic air pollutants such as sulphur dioxide and nitrogen dioxide by rain water.

Acidic salts are formed by partial replacement of a replaceable H^+ ion of an acid by a positive metal ion.

Alkanes are the simplest hydrocarbons in which each carbon is attached through single bonds with other atoms. They have general formula C_nH_{2n+2}.

Alkenes are unsaturated hydrocarbons having double bonds. They have general formula C_nH_{2n}.

Alkyl radicals are derivatives of alkanes. They are formed by the removal of one hydrogen atom from an alkane molecule.

Alkynes are unsaturated hydrocarbon having a triple bond in their molecules. They have general formula C_nH_{2n-2}.

Amino acids are organic compounds consisting of both amino and carboxyl groups.

Ammonical Liquor is a solution of ammonia gas in water.

Amphoteric is a substance that can behave both as an acid and as a base.

Arrhenius acid is a substance that contains hydrogen and produces H^+ ions in aqueous solution.

Arrhenius base is a substance that contains the hydroxyl group and produces hydroxide OH ions in aqueous solution.

Atmosphere is the envelope of different gases around the Earth. It extends continuously from the Earth's surface outwards without any boundary.

B

Basic salts are formed by the incomplete neutralization of a polyhydroxy base by an acid.

Bronsted-Lowry base is a substance that can accept a proton from another substance.

Bronsted-Lowry acid is a substance (molecule or ion) that can donate a proton to another substance.

C

Capillary action is the process by which water rises up from the roots of plants to leaves

Carbohydrates are macromolecules defined as polyhydroxy aldehydes or ketones or the organic compounds which produce polyhydroxy aldehydes or ketones on hydrolysis.

Catenation is linking of carbon atoms with one another through covalent bonds to form long chains or rings of carbon atoms.

Chemical equilibrium state is one at which forward reaction and reverse reaction takes place at equal rates but in opposite direction.

Coal Gas is mixture of hydrogen, methane and carbon monoxide.

Coal is blackish complex mixture of compounds of carbon, hydrogen and oxygen.

Coal Tar is a thick black liquid. It is a mixture of more than 200 different organic compounds, mostly aromatic.

Coke is 98% carbon. It is left behind as a residue of coal.

Concentration is a separating technique in which mineral is separated from **gangue** depending upon their wetting abilities.

Crude oil is dark brownish viscous liquid.

D

Destructive distillation is strong heating of coal in closed retorts in the absence of air.

Dynamic equilibrium state is one at which reaction does not stop, rate of forward and reverse reactions become equal to each other but take place in opposite direction.

E

Equilibrium constant is a ratio of the product of concentration of products raised to appropriate power of coefficient to the product of concentration of reactants raised to the appropriate power of coefficient as expressed in the balanced chemical equation.

F

Fatty acids are building blocks of lipids. They are long chain saturated or unsaturated carboxylic acids.

Functional group is defined as an atom or group of atoms which gives characteristic properties to organic compounds.

G

Greenhouse effect is rising of temperature because of trapping of heat energy by carbon dioxide gas in the atmosphere.

H

Hard water does not produce lather with soap.

Hydrocarbons are compounds made up of only two elements carbon and hydrogen.

Hydrogenation means addition of hydrogen in alkenes and alkynes.

I

Irreversible Reactions are those in which products do not recombine to form reactants.

Industrial waste is by-products (chemicals and waste materials) discharged either to open ground or to water channels.

L

Law of mass action rate of a chemical reaction is directly proportional to the product of the concentrations of its reactants raised to power equal to their number of moles as in the balanced chemical equation.

Lewis acid is a substance (molecule or ion) that can accept a pair of electrons.

Lewis base is a substance that can donate a pair of electrons.

Lipids are macromolecules made up of fatty acids.

M

Mesosphere is next to stratosphere and extends upto 85 kilometre from the Earth's surface

Metallurgy is the technique in which metals are extracted from their ores by applying different operations.

Mineral is a naturally occurring substance that contains a metal to be extracted.

Monosaccharides are the simplest sugars, which cannot be hydrolyzed. They consists of 3 to 9 carbon atoms.

N

Natural gas is a mixture of low molecular mass hydrocarbons. The main component about 85% is methane, other gases are ethane, propane, and butane.

Normal salts are formed by the total replacement of ionizable H^+ ions of an acid by a positive metal ion or NH_4^+ ion.

O

Oligosaccharides give 2 to 9 units of monosaccharides on hydrolysis

Ore is a natural deposit containing mineral of an element to be extracted.

Organic compounds are compounds of carbon and hydrogen and their derivatives.

Ozone hole is the region in which ozone layer depletes in atmosphere.

Ozone is an allotrope of oxygen. Its maximum concentration called **ozone layer** lies in stratosphere region about 25 to 30 km away from Earth' s surface.

P

Permanent hardness is because of presence of sulphates and chlorides salts of calcium and magnesium.

Pesticides are dangerous organic chemicals used to kill or control pests.

Petroleum is a dark brownish or greenish black coloured viscous liquid.

pH is the negative logarithm of molar concentration of the hydrogen ions.

Pollutants are waste materials that pollute air, water or soil.

Polysaccharides are the carbohydrates consisting of hundreds to thousands of monosaccharides.

Primary pollutants are the waste or exhaust products driven out because of

combustion of fossil fuels and organic matter.

Proteins are highly complicated nitrogenous compounds made up of amino acids.

R

Reduction means addition of nascent hydrogen.

Refining process is the separation of crude oil mixture into various useful products (fractions). It is carried out by a process called **fractional distillation**.

Reversible reactions are those in which products can recombine to form reactants.

Roasting is heating of concentrated ore in a furnace in the presence of air.

S

Salt is defined as an ionic compound composed of a metallic cation and non metallic anion

Saturated hydrocarbon is compound in which all the four valencies of carbon atoms are fully satisfied (saturated) by single bonds with other carbon atoms and hydrogen atoms.

Secondary pollutants are produced by the various reactions of primary pollutants with water.

Smelting is the further heating of the roasted ore, flux of sand and coke in a **blast furnace** in the presence of excess of air.

Soft Water is that produces good lather with soap

Stratosphere region covers the atmosphere from 12 to about 50 kilometres.

Strong acids and bases are those that can ionize completely.

Substitution reaction in which one or more hydrogen atoms of a saturated compound are replaced with some other atoms (like halogen).

T

Temporary hardness is because of presence of bicarbonates of calcium and magnesium.

Thermosphere lies beyond mesosphere. In this region temperature rises gradually.

Troposphere is just above the Earth's surface and extends upto 12 kilometre.

U

Unsaturated hydrocarbon are compounds in which the two carbon atoms are linked by a double or a triple bond.

W

Waterborne diseases are caused by drinking polluted water or eating food prepared with polluted water.

Water softening is removal of hard water ions (Mg^{2+}, Ca^{2+}).

Weak acids and bases are those which ionize partially in water.

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